



Realising Ambitions:

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Preface

Realising Ambitions, the 6th Annual Symposium of the United Kingdom and Ireland Engineering Education Research Network took place in Portsmouth during 1-2 November 2018.

It is a great privilege to present the proceedings of EERN UK&I 2018 to the engineering education community (research and practice). I hope that the developed papers will inspire your research and practice just as the conversations and experiences you had during the symposium here at Portsmouth.

It is very important that Engineering Education Research is encouraged in diverse ways both within and outside our higher education institutions. To this end, for the first time in the history of our network, awards were given to authors of original works presented at the symposium. The following awards were given out and the respective papers are included in the proceedings:

1. Emerging Scholar (Darren Carthy, pg. 69-74)
2. Most Original Contribution (Maria Giulia Ballatore, pg. 151-160)
3. ALT Most Innovative use of Technology in EER (Rafael Hidalgo, pg. 139-150)

The awards were possible due to our sponsors, The Institution of Engineering and Technology and the Association of Learning Technology, so a special thanks to both our sponsors for making this possible. We are hopeful that the awards are useful in helping you progress your research career.

We are thankful to all reviewers listed in this proceedings for meticulously reviewing papers as per the review process as well as to the authors who submitted developed versions of their work presented at the symposium in November. A special thanks also goes to Jane for putting together useful theme summaries which you will find at the start of each section of this work.

Manish Malik, the University of Portsmouth, UK.

On behalf of the Editorial team

Reflection from Keynote

In his keynote address, Prof Brian Bowe described the birth and growth of *CREATE*: a STEM education research group, at Technological University Dublin. Research activity within *CREATE* spans all levels of education from primary to higher, and is loosely divided into three areas: STEM & Mathematics; STEM & Society; and STEM & Cognition. The group currently has 25 members, which includes academic staff, visiting researchers, research interns and 13 PhD students. However, the group was originally established by Prof Bowe almost 20 years ago as a physics education research group (PERG). PERG was initially established to evaluate the implementation of problem-based learning within physics curricula. Rigorous evaluative studies soon evolved into research that examined different aspects of the pedagogy, such as approaches to learning, conceptual understanding, problem-solving, group dynamics, epistemological beliefs and the process of change in education. With funding from both national organisations and the European Commission, the group continued to grow and took on its first PhD student in 2002. By 2008, the group had expanded to include education research studies in chemistry, computer science and engineering. The growth accelerated by hosting visiting researchers and between 2018 and 2016 the group hosted eight Fulbright Scholars and three Fulbright Specialists. By 2013, engineering education research had become the predominant activity within *CREATE* and to reflect this, the group was renamed *CREATE*: Contribution to Research in Engineering & Applied Technology Education. One key strength of the group stems from the diversity of the members' backgrounds and disciplines, which include engineering, physics, chemistry, computer science, maths, sociology, education and philosophy. Current *CREATE* projects include studies examining issues such as sustainability and ethics in engineering education, professional and transversal skills, cognitive development and problem-solving, through collaborations with Universities across Ireland, Europe and USA.

Prof Bowe described lessons learned in establishing and growing an engineering education research in a context of very limited funding sources and in an environment where the benefits of education research are rarely understood or acknowledged. In this regard, the initial aim of a research group to establish an expertise and reputation in a particular area or specialism is often compromised by the need to attract funding through diversification. Prof Bowe stressed the importance of engaging with the engineering education research community through organisations such as SEFI and benefits of collaborations. He concluded by highlighting the multidisciplinary nature of engineering education research and the need to ensure this diversity is reflected within research groups and collaborations.

Introduction

Looking back on last November in Portsmouth, my abiding recollection is of the tremendous buzz in all of the meeting rooms. The desire to learn, share and question was evident in every interaction. For me, this suggested that the Network is really starting to realise its potential as a friendly and supportive environment in which to explore those topics most relevant to the future of Engineering Education and Engineering Education Research.

The inclusive and diverse nature of our community is something we should continue to promote, as it is the best way for us to appreciate the challenges and ideas that will help to identify the path we take as individual researchers, research teams or as a wider community. That community now numbers over 200 people which, from a very small start 10 years ago, is something we can all be proud of.

The diverse range of subjects explored in these proceedings is indicative of the many questions colleagues are asking and exploring across the UK and Ireland. Looking at this compilation, and there are some papers missing, there is a lot going on!

The symposium saw the creation of three Special Interest Groups in the areas of Research Methods, Maths and Inclusion and there was confirmation that the Spring Colloquium is here to stay. The 2nd Symposium took place in Dublin in early May 2019.

The diverse range of keynotes afforded us the opportunity to hear about the local challenges concerning the restoration of the Mary Rose Tudor warship, the cutting edge thinking of industry at IBM, the experiences of the Teaching Excellence Framework pilot and the practicalities of setting up an Engineering Education Research Group. In taking a broader view of Engineering Education, we were able to discuss ways in which the Network is able to challenge itself and the wider Engineering Education community. It is important that as a group we are willing to ask the hard questions and not only serve our students, colleagues and industry but also raise sometimes contentious issues in the area of policy.

To continue our work we are often reliant on our own energy and goodwill on the part of our institutions. Now, after 10 years and with the level of maturity we have achieved, we need to be pressing the case for more regular access to funding opportunities that will enable our work to continue to develop. In seeking to link Engineering Education Research to TEF and REF, we start to build a credible argument about the value of what we are doing – informed learning and teaching innovation coupled with a reality in bringing discipline research and education together.

I sincerely hope that you are finding the Network of value in a range of different ways. Please let me know if you have ideas about its ongoing development.

In closing I would like to thank Manish and the team at Portsmouth for a tremendous event. To colleagues from Ireland and beyond – you are always most welcome. To the members of the Network Steering Group, please keep up the great work. Finally to everyone who participated or has an interest in improving Engineering Education through research and scholarship, thank you and here's to an even brighter future.



I will look forward to welcoming you to the University of Warwick towards the end of 2019.
Until then take care and enjoy!

Professor Robin Clark

Chair of the UK and Ireland Engineering Education Network

Reflections from network vice-chair

In the year since our 5th Symposium took place in London the Network has seen further growth in membership which would appear to show a developing maturity for the Network as we approach 10% of our membership being beyond the geographical boundaries of the UK and Ireland. Consolidation has also allowed the addition of a Spring Colloquium to our calendar alongside the various conversations happening on social media, especially amongst the Newer Researchers Network.

Through consideration of the wide range of work that has been undertaken and presented in these proceedings supported by conversations at the Symposium it is becoming very apparent that the focus on our students' ability to 'do' rather than what they 'know' is fortunately becoming much more evident. The community is attempting to overcome the illusory superiority evidenced by much of the material promoting undergraduate engineering programmes on HEIs web-sites.

It does not come as a surprise that a focus upon more authentic learning activities is leading to a welcome and more critical approach to the design and evaluation of group, peer and inclusive learning activities. As a counter to this it is not clear, at this point, that research in formative and summative assessment practice is keeping abreast of developing learning activities. The root cause for this may be that this is where the accountability of module activity butts against programme and management systems with their embedded conservatism. It is a function of publications such as this to provide the evidence base for this much needed programme wide innovation, incorporating the full integration of workplace facing, outcomes based, assessment practice within engineering education.

At a time when many universities are creating extensive and glossy marketing materials which promote their attempts to address Global issues through scientific research it is a disappointment that HE education practice research remains overlooked as another route to the same ends. A more enlightened and skilled population is required to enable scientific developments to reach full fruition and impact on the lives of all communities. This is why universities should also be investing in discipline focussed educational research, enhancing their capability and effectiveness in their core function. Pockets of excellence will always lead change but for change to become embedded, and offer better outcomes for a wider range of students, then the capacity to lead effective learning activities must become expected of all academics who play a part in supporting learning. Now is the time for engineering education research to become more strategic in demonstrating the value of converting research into evidence based practice to the benefit of all students, during their course, after their course and to their employers.

Theme Summary: Teamwork and Skills Development

The importance given to teamwork and skills development across the Engineering Education Research community is reflected in the fact that this topic represents the most papers in this document with 10 very different perspectives given. Starting with a novel twist on using group design projects to teach project management and teamwork, the first paper kicks off with a highly informative critique of the application of the 'real facets of engineering teamwork' to an Engineering Education setting. Written by Nicols, University of Sheffield, the paper discusses how, by introducing the concept of 'industrial espionage', into group work students learn far more about team working and trust than they would in undertaking a more 'standardised' group work task.

Following this, work by Cruz & Saunders-Smiths whose work in introducing a 'Boot Camp' style training week to the curriculum is proving to be successful at Delft University in the Netherlands.

Continuing the theme of team working within 'real-life' settings, Lucas et al, University of Warwick, show how peer assessment in group projects can successfully promote key employability skills in Engineering Education. This is followed by an Australian perspective from Blackmore et al, Australian National University, who explore students' perceptions of individual and group performance with the 'Capstone Project Module'.

A slightly different take on employability is then offered by Munoz-Escalona and Dunn, Glasgow Caledonia and the University of the West of Scotland, who show how encouraging creativity in engineering students can result in the development of strong team working skills. Interestingly this paper deals not only with multi-disciplinary teams but also discusses multicultural working amongst students.

Two papers introducing the early stages of PhD Projects currently being undertaken at TU Dublin are given by Carthy et al and Beagon & Bowe. Carthy's paper draws attention to the potential advantages of using psychometric testing to align students to professional roles whilst Beagon & Bowe begin to explore academics' perspectives of teaching professional skills.

The next two papers in this section both refer to work conducted at Aston University. The first of these from Peters looks at the use of ill-formed problems in Maths education whilst a paper by Andrews et al identifies the key skills and competencies second and final year students believe they bring to Maths Peer Tutoring at Engineering Foundation Year level.

The final paper is part of a PhD case study conducted at Lancaster and Portsmouth University given by Malik. Malik's work looks at development of team trust and conflict management skills within a computer orchestrated group learning environment, COGLE and highlights the complex interrelationship between trust and conflict resolution.

Paper 1: A novel twist on a group design project to teach real project management and teamwork skills

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KEY WORDS: Group project, teamwork, trust, skills redundancy, onboarding

ABSTRACT

This study explores the introduction of a novel element to an undergraduate group design and build project. It is designed to give students exposure to and experience of real facets of teamwork dynamics often experienced by real engineers but seldom by undergraduates. They are namely (i) team trust, (ii) skills redundancy, (iii) onboarding. The technique is applied to a second year interdisciplinary engineering design module, and data is presented from two surveys completed by the students before and after the task, indicating how they felt about the unique twist, and what they felt it taught them. In conclusion, the method presented gives an effective and enjoyable first experience of real teamwork elements for engineering undergraduates.

INTRODUCTION

This paper focuses on a design and build project set for second year undergraduate general engineering students. It forms half of a 15 credit module (out of 120 credits in the year). The 33 students on the course were divided into 7 groups of 4 or 5, and each group was given the same broad brief of designing and building an autonomous swimming robot for surveying watercourses in search of pollution. The purpose of the project is to enable students to apply the technical knowledge learnt in other modules while appreciating the

importance of an interdisciplinary approach, while also equipping them with professional skills to enable them to stand out in the graduate jobs marketplace. The initial stage of the project involved use of project management tools and systems engineering approaches to develop a concept for prototyping. It is over the course of this initial stage that the present study took place.

LITERATURE REVIEW / RATIONALE

Employability skills are seen as increasingly important in engineering graduates (Devambatla & Nalla, 2015; Paul, 2015), with many employers expecting graduates to be equipped with skills including team working, project management, finance, evaluation etc. Teamwork in particular is an essential part of being a professional engineer that most universities attempt to prepare students for.

There is however an increasing demand for universities to teach more employability skills, including those not often experienced in undergraduate education. This has been highlighted by various authors who experimented with methods of embedding employability skills in undergraduate group projects (Saparon, et al., 2017; Herrera, et al., 2017). In particular, dealing with team dynamics and, importantly, changing team dynamics are seen as key employability skills for new graduates to possess. Some universities explicitly teach team dynamics (Ostafichuk et al., 2010), and the idea reaches back two decades (Brown & Dobbie, 1999) but sadly the “team dynamics” element of project work is traditionally relatively static, with few if any changes in team structure and composition; this is not reflective of true teamwork in industry. Linked to the dynamic nature of real teams is the notion of team trust, which has been extensively explored in the context of industrial teams where there is a potential for betrayal for personal gain (Chan, 2003; Costa, 2003). If universities wish to provide students with these kinds of skills then new techniques are required to integrate them into existing group project practices without compromising the conveyance of technical knowledge and experience.

MEng Engineering is a relatively new degree course that prides itself on implementing new and exciting teaching methods. In 2017 it was hypothesised that integrating an industrial espionage element into a group project would enable key employability skills to be introduced in an engaging way, because corporate espionage is (a) a prevalent occurrence that is seldom discussed with undergraduates, with recent high-profile cases (Huffman, 2018); (b) a topic glamourised by Hollywood via movies such as *Cypher* (2002), *Duplicity* (2009) and *Inception* (2010); (c) ideal for implementation via role play, a method shown to have potential to enhance student engagement (Stevens, 2015). An important part of

introducing new methodologies is to assess their impact and effectiveness (Moraros, et al., 2015), and that is the motivation for the present study.

AIM AND OBJECTIVES

This study set out to evaluate the potential for integrating the concept of industrial espionage into undergraduate group projects in order to teach several employability skills seldom experienced in undergraduate engineering education. As discussed in the previous section, the choice of integrating industrial espionage was made due to its prevalence, Hollywood glamourisation and suitability for role play, and also due to the interesting juxtaposition of using a practise based on betraying one's team to help students to develop teamwork skills.

Objective 1: Characterise student opinion on using industrial espionage as a learning tool.

Objective 2: Evaluate the effectiveness of using industrial espionage as a learning tool.

METHODOLOGICAL APPROACH

The student group was comprised on 33 second year students. All students were UK citizens, and 4 of the students were female, with all being aged between 19 and 21. During the first lecture, the project was introduced to the students, along with details of all assessments and resources available. The groups were then given a short presentation introducing them to the concept of industrial espionage, with historical examples, and were told that one person in each group would be discretely invited by email to become a mole. The moles would feed information about their team's ideas to the module leader, who would then share each mole's information with one of the other groups. The teams were told that after the initial design stage (approximately 3-4 weeks) the moles would be moving to the group that they had been anonymously supplying information to. The mole in each group was selected at random and emailed discretely. The moles did not know which group their intelligence was being fed to, and the groups did not know from whom the information originated. They could choose to provide as much or as little information as they liked, with most engaging significantly, and only one choosing to provide no information.

This would introduce the students to three key concepts: (i) team trust – the groups would have to deal with the knowledge that one unknown person on the team could not be trusted; (2) skill redundancy – if a key element of the project was assigned to just one person, and that person turned out to be the mole, then the group would suffer; (3) onboarding – the teams would have to deal with a new member joining their team part-way through the project, finding them a role and understanding their place in the team.

While the primary aim is to provide quantitative assessment of effectiveness and student perception, some informal discussion would also be conducted with the students immediately after introducing the mole element in order to qualitatively assess their reaction, by asking how the mole element would affect how they operate as a team. The effectiveness and student perception of the mole element would be quantitatively evaluated via two surveys; one set just after the mole concept was introduced to the students, and one after the project was completed. The surveys consisted of structured questions using the Likert scale, and an open opportunity to provide comments. This would enable quantitative comparison of the students' opinions on the mole element before and after it takes place, along with their perception of its effectiveness.

The survey questions asked just after the mole concept was introduced and moles selected were:

- I like the idea of having moles in teams (Likert scale)
- I would like to be a mole (Likert scale)
- Any comments? (Free text entry)

The survey questions asked after the project was completed were:

- I liked the idea of having moles in teams (Likert scale)
- I would have liked to be a mole (Likert scale)
- This project taught me about team trust (Likert scale)
- This project taught me about skills redundancy (Likert scale)
- This project taught me about onboarding (Likert scale)
- Any comments? (Free text entry).

KEY FINDINGS & DISCUSSION

Though the main aim of this study was to produce quantitative data regarding student opinion of the mole element and effectiveness of the mole element, discussions with students revealed some initial qualitative insight. These discussions took place within the classroom immediately after introducing the mole element, while groups were discussing the implications amongst themselves, and involved asking students how the mole element would change the way they operated as a team. (a) most students felt that despite the fact one team member could not be trusted, they must assume that the team can all be trusted in order to make progress; (b) most teams (some with prompting) realised that they must ensure all roles within the team have a deputy in order to prepare for one of the team leaving; (c) the teams realised that they would have to be flexible in the working dynamic in order to integrate a new team member part-way through.

The results for the survey questions about liking the mole idea are shown in Figure 1. It can be seen that immediately after the mole concept was introduced (blue) several students were strongly against the idea, most were neutral or liked the idea, and a few strongly liked it. After the students has experienced the mole concept play out, the spread of opinion was much less broad, and generally more positive, with only 10% of students not liking the idea, and none strongly.

Figure 1: Did students like the mole idea?

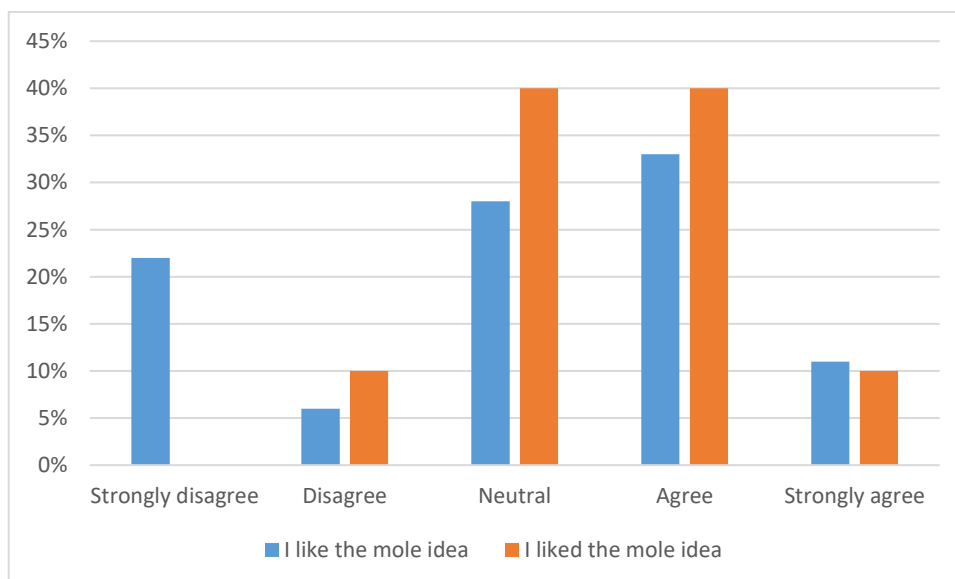


Figure 2 shows the students' responses regarding wanting to be a mole. Again the spread was very broad prior to the experience, and much more condensed afterward, but with an average response of neutrality in both cases. It seems that some students naturally like this kind of role, while others do not. Note that both of these questions were posed to the entire sample population, including those who were moles.

Figure 2: Would students like to be a mole?

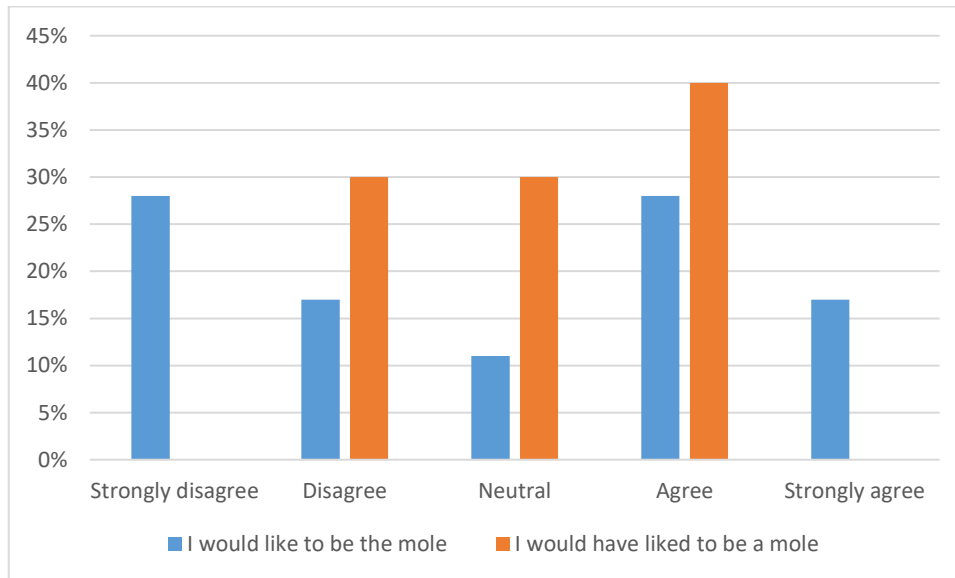
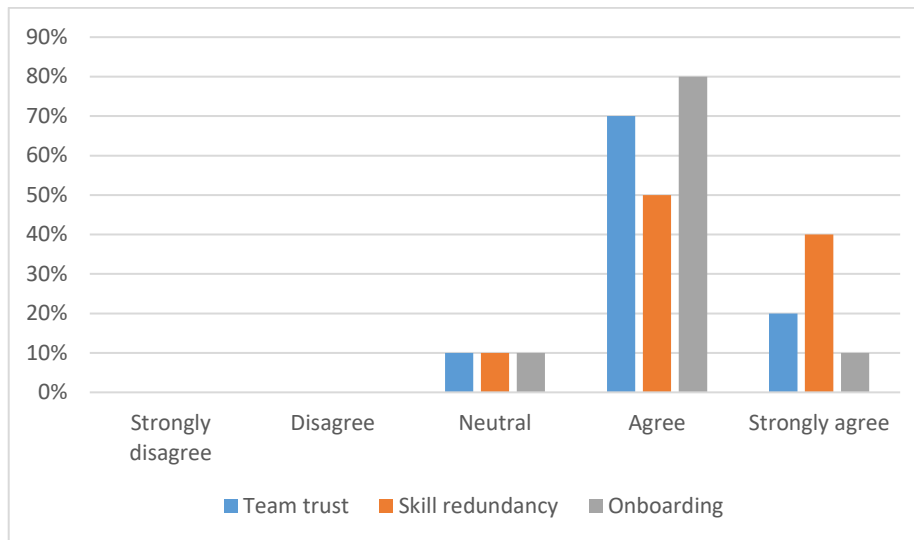


Figure 3 shows the responses to the remaining post-project questions regarding employability skills. It can be seen that the objective of teaching students about team trust, skills redundancy, and onboarding was achieved. Most students agreed or strongly agreed that the mole element of the project had helped them to learn these skills, with no students disagreeing. It is thus thought that this experience will support students in securing employment, due to the importance that employers increasingly place on team working skills and employee reliability (Devambatla & Nalla, 2015; Chan, 2003; Costa, 2003).

Overall these data show that the desired benefits of teaching students about skills redundancy, onboarding, and team trust were largely successfully conveyed. It should also be noted that the students generally found the mole element to be different and exciting. The moles were revealed via a fun activity asking each team to try to identify the mole amongst them, with prizes for successful moles or teams. The free text responses included phrases such as "I'm so happy I'm the mole", "really enjoyable project!" and "Definitely learnt a lot".

Figure 3: Employability skills



Challenges of operating the mole element of the project include:

- 1) Ensuring engagement of the moles. This was largely achieved by emphasising to students that the moles would be joining the teams that they provide information to, thus giving them an incentive to pass on the good ideas.
- 2) Ensuring that moles kept their identity secret. This was achieved by explaining in advance that successful moles would win a prize, and playing on their innate competitive nature.

CONCLUSIONS & RECOMMENDATIONS

This paper has introduced a novel way of teaching several essential professional skills to undergraduate engineers via the concept of industrial espionage. It has been shown to be very effective, and students on the whole very much enjoyed and engaged with the concept of having a mole within the teams. It successfully taught students three key employability skills of team trust, onboarding, and skills redundancy. Recommendations include:

- 1) Ensure that the benefits of engaging in the process are highlighted so that moles take their role seriously.
- 2) Foster an atmosphere of playful competition to keep students engaged and incentivise participation.

- 3) Consider carefully the selection of the moles; one of the moles was not pleased about being randomly selected - an alternative might be to ask for volunteers and randomly selecting from those willing.

It is highly recommended that this study is followed by a larger study that includes a control group of students who do not participate in the mole element in order to validate the findings of this study. An important line of enquiry is to explore how the potential of having a mole within the team affects the students' trust in their team members. The new study should employ validated instruments, for example measuring team trust based on existing valid survey questions and formats.

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Paper 2: Pilot study boot camp: professional engineering roles experienced in a week

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KEYWORDS: One-week course, Boot camp, Professional Engineering Roles, Pilot Study, Transversal Competencies

ABSTRACT

Engineering education has recognised that engineering graduates require transversal competencies like communication, teamwork and problem-solving alongside technical competencies. The importance of transversal competencies has grown and curriculum elements have been implemented to stimulate these competencies. However, a gap still exists between what education provides and practice requires. To reduce this gap and increase engineering student's employability, lecturers need to expose students to transversal competencies and allow them to practice them throughout the curriculum. For the purpose to stimulate the development of students' transversal competencies necessary to engineering careers, a week-long style boot camp course was designed and implemented at the Delft University of Technology. In this study, a pre and post-questionnaire and a reflection were administered to students to evaluate the transversal competencies encountered and acquired by the students during the course, their engineering role awareness and course efficacy. Findings revealed that students improve in their transversal competencies including presentation skills, interdisciplinary thinking, innovation and creativity, and professional engineering role knowledge during the course. However, improvements in the attracting of students to the course and specification of the assignment need to be addressed for the next run of this course scheduled for next year. Lecturers are encouraged to implement authentic learning experiences like this, as these experiences provide students with awareness and practice of the engineering roles and stimulate students' transversal competency development necessary to be successful in those roles.

INTRODUCTION

Globalisation and rapid changes in technology since the 2000s have changed the engineering sector. This shift has led to industry seeking for engineering graduates who are equipped with not only technical but transversal competencies like creativity and innovation, communication skills, teamworking skills, and lifelong learning skills (Spinks et al. 2006). To develop these competencies a week course was implemented at the Delft University of Technology, the Netherlands. This course was also developed to provide students with awareness of and experience with the three professional engineering roles (Product Leadership, Operational Excellence, and Customer Intimacy) of the labour market established by the researchers involved in the European project PREFER (Professional Roles and Employability of Future EngineerRs). More information about the project and roles can be found in (Craps 2017) and (Craps 2018).

This study aims at evaluating the boot camp course and students' development of and exposure to transversal competencies and engineering roles knowledge. For this purpose, a mixed-method approach is used (pre- and post-questionnaires, individual reflections and feedback).

LITERATURE REVIEW / RATIONALE

According to the European Skills Panorama study (European Commission 2016b), European employers still face recruitment problems for STEM skill labour. More specifically in our context, the Netherlands expects a growth of 2.8% in shortage occupation with engineering professionals until 2020 (European Commission 2016a). The reasons for this are the short supply of workers compared to the demand, and the great percentage (38%) of graduates with a technical background who rather choose a non-technical profession (Saunders-Smits, 2008). Engineering education has responded to these issues by trying to increase the number of students and making engineering education more attractive by increasing their emphasis on competencies including communication, problem solving, working in teams, and lifelong learning (Passow and Passow 2017) and by introducing new teaching methods, as alternatives to traditional lecture-based methods, like active learning, collaborative learning, cooperative learning, and problem-based learning (Prince 2004).

In 1996, project-based learning and transversal competencies were introduced in the curriculum of Aerospace Engineering at Delft University of Technology (Saunders-Smits 2008). Since then, five design projects started to run in the three years of its Bachelor degree which were renewed and given a more central role in the bachelor revision of 2008 (Saunders-Smits et al. 2012). In these courses, students acquire both knowledge through learning by doing and competencies in teamwork, people management, networking, and

oral and written communication, as well as problem-solving, analytical and synthesizing skills (Saunders-Smiths 2008). Moreover, at Master level, this concern to integrate transversal competencies in the curriculum has been present. For instance, the mandatory internship which has been a longstanding part of the Aerospace Curriculum promotes student employability skills (Kamp and Verdegaal 2015) and the Forensic Engineering course which in 2009 due to the change of lecturers gave more emphasis to critical thinking (Saunders-Smiths et al. 2016, Saunders-Smiths et al. 2015), and later on to communication and lifelong learning (Leandro Cruz and Saunders-Smiths 2018).

While curriculum elements focus on the development of transversal competencies to respond to industry demands including collaborative skills and problem-solving (Hadgraft 2018), and leadership skills (Willmot 2017), none reports on projects specifically aligning these competencies to professional engineering roles as was done in the week-long boot camp style course as reported on in this paper.

COURSE DESCRIPTION

The boot camp was designed as a week-long 2 ECTS course in which students in small groups (3-5) work on a design problem, intensively. The learning objectives of the course were:

- Plan and manage time and tasks as a team
- Be creative and innovative to invent, design and develop a product
- Identify solutions to optimise products
- Present, convey and persuade stakeholders about product efficacy
- Engage in lifelong learning through reflections on own strengths and weaknesses, and own future engineering career

The project objective for the students was to create a learning activity or product for primary school children that allows them to discover what an engineer is. During the first phase of the boot camp, the team was told about the different professional roles an engineer can have and they were given the assignment. After that, the team was expected to interview a number of primary school teachers who volunteered to act as a client so that students can better understand their customer. Based on this information, students would generate ideas, analyse the feasibility of their ideas and choose one to design and build. At the end of the first day, the team is expected to deliver a pitch that explains what they propose to develop and what their plan is to achieve it. The team had to create a teaching activity or product. The students' prototype must be ready by day 3 at mid-day, and the team was expected to present and demonstrate their prototype to a selection of primary school teachers. Feedback on their design and presentation was provided to students in this phase of the boot camp. In the second phase of the boot camp, the team was expected to optimise their product. Further,

based on the feedback received, students were expected to think about variables (cost, materials, etc.) which they could alter to boost their product. Their final product or teaching activity had to be ready by day 5 at mid-day after which the boot camp was concluded by the presentation of the final product and their marketing slogan. A workshop on creativity and Innovation and a workshop on Argumentation and Persuasion were included in the boot camp.

The course was offered as an elective for Master and PhD students and although 13 students registered on the first day only 3 students showed up.

AIM AND OBJECTIVES / RESEARCH QUESTION(S)

The aims of this study were threefold. First, to measure students' improvement of a set of transversal competencies. Second, to assess students' knowledge of the three engineering roles. Finally, to evaluate the implementation of the one-week long boot camp style course which intends to, on the one hand, stimulate the transversal competencies, and on the other hand provide awareness and practice of the professional engineering roles of the labour market.

The following research questions were addressed in this study:

- Do students improve their competencies (entrepreneurial, innovation, teamwork, communication, lifelong learning) during the period of the boot camp?
- Are students aware of the three engineering roles after attending the course?
- Does the boot camp concept work to assist students in develop transversal competencies and practice the engineering roles?

METHODOLOGICAL APPROACH

The three research questions were answered using mixed-method research. This approach was chosen to strive for triangulation of results from different methods (qualitative and quantitative) (Johnson and Onwuegbuzie 2004). The quantitative method was selected to generate results independent of the researcher with statistical analysis, however, due to the low sample size (3 respondents), the use of a qualitative approach turned out to be more valuable to study the cases in detail. The following methods were used:

- Pre- and post-questionnaires (N = 2, quantitative and qualitative methods): The pre-questionnaire was administered at the beginning (day 1) and the post-questionnaire after the conclusion of the course (three weeks after, in the feedback session of the

course). Students were asked to rate themselves on their overall competency level for each role on a scale of 1 to 10 (with 1 – very poor and 10 - excellent), to choose the professional role they most preferred, and to indicate their perceived level of expertise (absent, basic, advanced or expert) in each of the 36 competencies listed. In the post-questionnaire, the questions of the pre-questionnaire were repeated. Additionally, a question asking students about what they felt they learned during the course was added, along with a section with questions evaluating the course itself.

- Individual reflections (N = 3, qualitative method): The first part of the reflection asked students about their understanding of the professional engineering roles. Questions asking respondents to define each role and to name three essential competencies for each role were asked. The other part of the reflection was about students' competency experience during the course. For example, which three competencies did they perceive to have developed in the course and a competency they found they still need to improve on. In addition, based on students' development and experience of the engineering roles during the course, they were asked to select the role they would like to pursue in their first job after graduation.
- Feedback (N = 2, qualitative method): Conducted three weeks after the completion of the course. Students were asked whether they would recommend this course to others and why and what improvements needed to be made to the course.

KEY FINDINGS

Competency improvement

Students' competency improvement during the boot camp and their overall perception of competency level for each role are present in Table 1 and Table 2 respectively.

Engineering roles knowledge

Students defined *Product Leadership* as the innovator or developer of innovative solutions. The *Operational Excellence* was described as the engineer who masters process, outcomes and dependencies and therefore is able to optimise or improve the efficiency of the products and processes. Finally, *Customer Intimacy* interacts closely with the customers and comes up with solutions according to their needs or satisfaction.

Besides defining the roles, students named three essential competencies for each role (Table 3).

Table 1 - Competencies improved and to improve during the course according to students' perspectives. Results from pre- and post-questionnaires (N = 2) and reflections (N = 3).

Competencies improved (Pre- and post-questionnaires)	N	Competencies improved (Reflections)	N	Competencies to improve (Reflections)	N
Value/cost consciousness	2	Planning & Organisation	2	Teamwork with international teams	1
Pitching skills	2	Creativity & Innovation	1	Communication skills	1
Business acumen	1	Out of the box thinking	1	Initiative	1
Risk tolerance	1	Presentation skills	1		
Negotiation skills	1	Patience	1		
Critical thinking	1	Stress resistance	1		
Adaptive communication style	1	Interdisciplinary teamwork	1		
Idea implementation	1	Client focus	1		
Ideation	1				
Presentation skills	1				
Self-confidence	1				
Listening skills	1				
Interdisciplinary thinking	1				
Give constructive feedback	1				

Table 2 - Grade given by students (N = 2) at the beginning and end of the course to their overall competency level for each role on a scale of 1 (very poor) to 10 (excellent).

Students	Product Leadership		Operational Excellence		Customer Intimacy	
	Pre	Post	Pre	Post	Pre	Post
1	5	8	5	8	6	7
2	9	9	9	8	6	9

Table 3 – Competencies selected by students per role. N is the number of students who selected the competencies.

Product Leadership	N	Operational Excellence	N	Customer Intimacy	N
Vision	3	Conceptualisation	2	Networking	3
Innovation	2	Planning & organisation	2	Negotiation skills	2
Out of the box thinking	1	Solution oriented	1	Stress resistance	1
Scientific knowledge	1	Initiative	1	Client focus	1
Determination	1	Decision making	1	Outspoken	1
		Attention to detail	1		
		Perfectionism	1		

Course evaluation

The second part of the post-questionnaire was analysed to evaluate the feasibility of the boot camp course. The findings showed that the activities provided in the course greatly or somewhat contributed to students awareness and practice of the engineering roles.

Regarding the organisation of the course, students were satisfied with the course duration and workload activities of the course. They appreciated feedback and working in teams rather than individually in an assignment like this. However, students perceived unclearness in expectations and definition of the assignment.

Based on students' course evaluation, they suggested that we could improve on the definition of the expectations, tasks and end goals. They also mentioned that the initial communication with the students at the registration could be better and the commitment of more students was needed especially to create the spirit of competition which triggers engagement of the teams with the assignment and stimulate teams to perform better.

Overall, the two students, who were asked in the feedback session whether they would recommend the course to other students, said they would recommend it. A student mentioned that he wanted to make a break in his research and he found this course nice and enjoyable to work on something very different. Another student argued that this course is very different from other courses because it is very good to develop soft skills like working in teams of unknown people and of different cultures and personalities, as well as to gain persuasion skills like he had the opportunity to develop in one of the workshops.

DISCUSSION

Courses like this week-long style boot camp, which provide an authentic experience of real-world challenges, facilitate students' learning of transversal competencies as present in other similar approaches in the literature (Willmot 2017, Hadgraft 2018). However, it is the first time that transversal competencies are aligned to professional engineering roles. Firstly, the findings triangulated between the questionnaires and reflections seem to suggest that the boot camp stimulated students presentation skills, creativity, innovation and work in interdisciplinary teams (Table 1). Secondly, this course contributed to developing students' awareness and practice of the engineering roles. Students increased their knowledge about these engineering roles (Table 3) and they perceived improvement of competency level in each role (Table 2). Although some findings were extracted from the chosen methodology from the qualitative approach, more data should be collected to better assess the impact of the boot camp. The course will be rerun again next year.

Conducting active learning is challenging and it takes some time and iterations to design an ideal course. Improvements in the communication with the students and specification of the assignment will be taken into consideration in the second implementation of the boot camp.

Small changes in the curriculum like this will hopefully encourage more lecturers to embrace active learning as active learning creates an environment that facilitates student learning and practising of transversal competencies and raise student awareness of their possibilities for future careers which traditional educational approaches cannot provide.

CONCLUSIONS / RECOMMENDATIONS

The aim of this study was to assess the first implementation of a week course at the Delft University of Technology in terms of students' competency development, engineering roles awareness and course efficacy.

Positive outcomes of the first pilot study were that students develop transversal competencies including presentation skills, interdisciplinary thinking, innovation and creativity during the course; students gained knowledge about the engineering professional roles; and that the course is effective in providing an authentic experience of the engineering professional roles and transversal competencies needed for those roles.

On the negative side, the study showed that improvements need to be made in improving the low student attendance, limiting the width of the assignment, and better addressing the expectations students have from the course.

Conducting active learning is challenging and it takes some time and iterations to design an ideal course. Therefore, the authors will take into consideration the lessons learned in the first implementation of the boot camp and will repeat the study on a larger population.

The authors strongly recommend more of this type of initiatives in engineering curricula to stimulate students' transversal competencies as well as give them an authentic learning experience to the engineering roles which will be useful for their future career.

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Paper 3: Towards a competency-based peer assessment for engineering group projects using skill descriptors

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KEY WORDS: Peer Review, Group Work, Assessment, Employability

ABSTRACT

Over the past two years, the School of Engineering at Warwick has been considering approaches to group assessment with a particular interest in aligning assessment criteria with the skills evaluated by companies during assessment centre group-work exercises. Whereas assessment centres can benefit from observers to record and monitor individual contribution, in academia it is more common to utilise peer review. Two issues were noted by industrial fellows in contrast with their experience outside of academia: establishing and identifying ideal team behaviour and the individual's role within (in contrast with typical leadership and group behaviour) and, secondly, the method of awarding marks to individuals within a group. We therefore developed a new peer assessment system which focuses on competency descriptors and levels of success instead of numerical scores. The descriptors are carefully chosen to encourage team work rather than reward leadership which risks creating 'pseudo-groups'. A pilot run of the system used mean-weighting of the underlying numerical scores to normalize an individual's assessment of their group members. In further work, we plan to investigate how the peer-review system works for students from different backgrounds including race, gender and disabilities.

This work-in-progress paper describes the background and on-going development of the proposed peer assessment system.

INTRODUCTION

Assessed group work is a prevalent feature of undergraduate Engineering courses and is required to meet learning outcomes as defined by AHEP 3 (Table 1, Engineering Council, 2014). Group work nurtures skills that are valued by employers including oral communication, negotiation and other interpersonal skills (Chin, 2010). Thus, the ability to work in a team is seen to be a strong indicator of employability and so is commonly assessed through competency-based interviews, group exercises, and role-play scenarios. Whilst group work itself is an effective learning activity for developing these skills, it is important to reflect on them by giving and receiving feedback on these behaviours. The ability to reflect and give feedback are further an essential life-long professional skill as defined by UK-SPEC (Table 2, Engineering Council).

Table 1: AHEP 3 Learning Outcomes

Engineering Practice	Understanding of different roles within an engineering team and the ability to exercise initiative and personal responsibility, which may be as a team member or leader.
Additional General Skills	Exercise initiative and personal responsibility, which may be as a team member or leader

The assessment of individuals within a group can give rise to tensions between group members, who may become more concerned with their mark rather than the outcome of the project. The use of peer assessment here refers to students marking each other's contribution to group work. This can be fraught with difficulty due to game playing and unequal perceptions of a team member's specific contributions, often due to the diversity of the student population.

In the existing peer assessment system, individual marks for group projects are based upon the relative technical contribution that the other team members believe the student had made to the project. A downside of this approach is that it encourages the students to take a task-based perspective towards team performance. Engineering companies have recognized limitations of such an approach: strong team performance does not consist of just getting the project completed, but also *how* the project was approached. Typically, engineering firms seek to measure the performance of employees against a competency-based framework, measuring more than technical ability (Soderquist et al., 2010).

Table 2: Extract from UK-SPEC

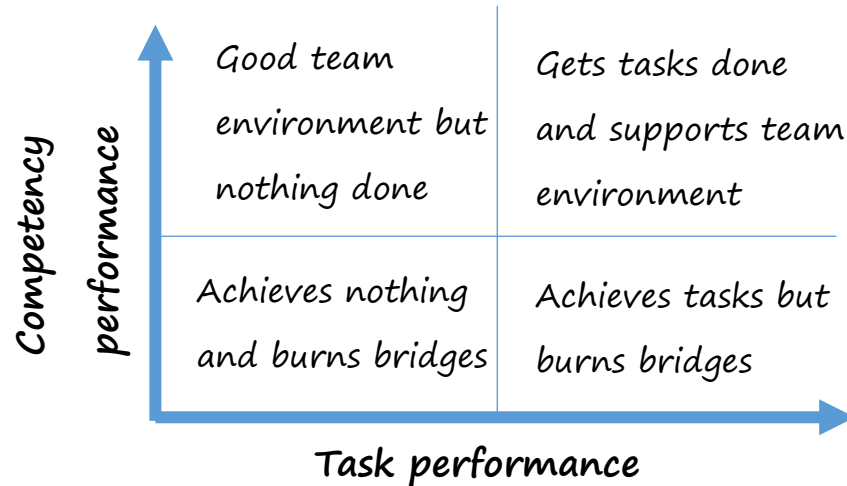
C3	Lead teams and develop staff to meet changing technical and managerial needs	Carry out/contribute to staff appraisals. Plan/contribute to the training and development of staff. Gather evidence from colleagues of the management, assessment and feedback that you have provided. Carry out/contribute to disciplinary procedures.
	<p>This could include an ability to:</p> <ul style="list-style-type: none"> • Agree objectives and work plans with teams and individuals • Identify team and individual needs, and plan for their development • Reinforce team commitment to professional standards • Lead and support team and individual development • Assess team and individual performance and provide feedback 	

A second issue is how the individual marks are calculated. Previously, a mean-weighted system was used with a fixed number of marks available for distribution within a group. Thus, someone must receive a lower grade in order for another to be rewarded with a higher score. Many students feel under increasing pressure to succeed with some commentators ascribing increase in part due to the increased financial burden of attending university since the change to student fees in 2012 (Bhardwa, 2017). It became evident over a number of years that such a grading system could be gamed by the students and there were particular concerns in cases where some group members had colluded to exclude other students in the group. Anecdotally, academically strong students report pleasure at being grouped with weaker students since there are more marks made available for them. The authors therefore wish to avoid any system which compares individual performance to a single group average.

The final consideration is whether group-work is an effective mechanism for technical learning. Whereas group working is clearly efficient for task completion and enables students to take advantage of each other's knowledge and skills (which is useful in industry), the downside is that some students do not achieve the technical learning outcomes. Although it seems acceptable to reduce an individual mark due to underperformance, to inflate a mark beyond the technical merit does not align with marks received for achievement of technical learning outcomes (unless those outcomes include teamworking skill and other group behaviour). There is therefore a pedagogic aim to prevent students from dividing work between them and simply reporting progress during team meetings. These 'psuedo-groups' were found to be common in the existing group-work in the School.

Since members of groups saw each other as competitors for points, they weren't motivated to share knowledge and therefore restricted technical learning to a few members.

Figure 1 Task vs Competency



LITERATURE REVIEW / RATIONALE

Experience shows that graduates often have under-developed team-working skills. This is supported by recent feedback from graduate recruiters and aligns closely with previous research, which has identified a competence gap between the teamwork skills employers require compared to those developed in undergraduate courses – particularly in Engineering (Willey and Gardner, 2008; Martin et al, 2005). Group projects and collaborative tasks often provide opportunities for individuals to interact with one another, but do not routinely emphasise or facilitate the development of team-working skills (Natishan et al, 2000). It is implicitly assumed that these skills are either already in place or will mature naturally with practice; but this may not always be the case – especially among individuals for whom social interactions can be challenging. Boud and Falchikov (2007) and Keppell et al (2006) advocate that curriculum and assessment design should promote and encourage development of these skills, and we view peer assessment of team performance to serve a key function in this regard. However, it is important that this activity is not relegated to simply scoring peers' performance and instead includes a formative component that informs future development.

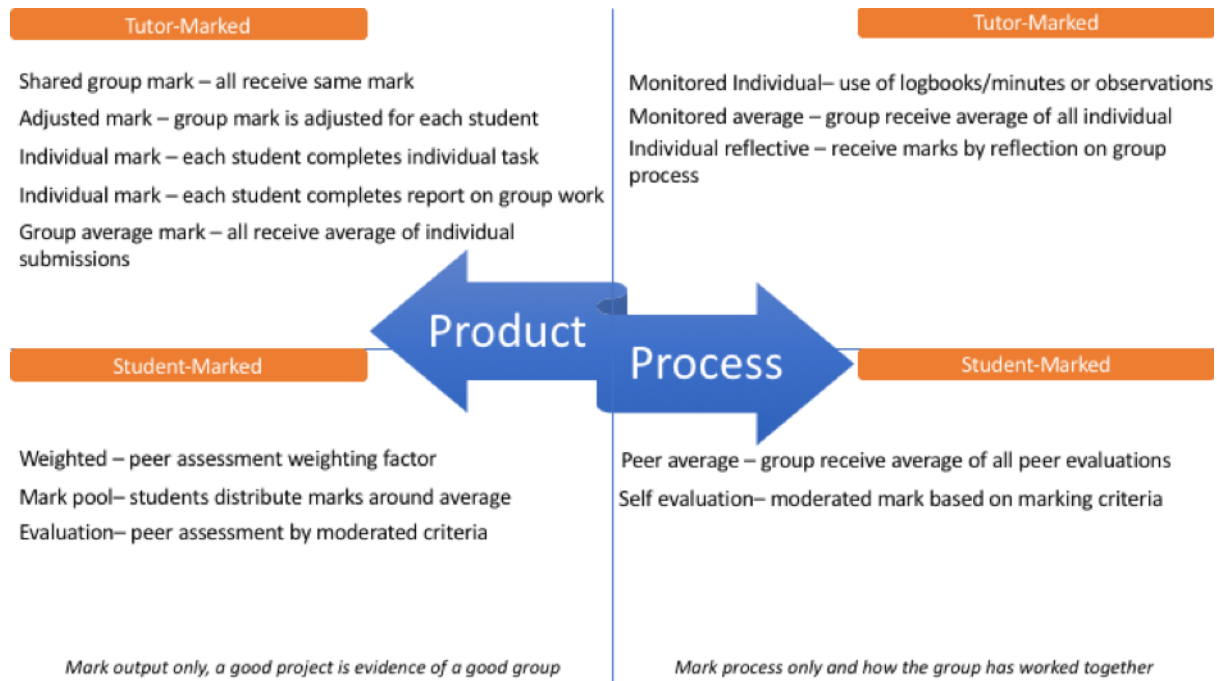
The terms “group” and “team” are often used interchangeably, but there are important differences highlighted in (managerial) literature. Fisher and Hunter’s (1997) review outlines that a team is a special designation for a group of individuals that share common goals and an awareness of the nature and complementarity of their respective skills and talents. There is also a notion of shared accountability and “responsibility for outcomes for their organizations” (Sundstrom et al, 1990, p.120). These ideas are developed by Söderhjelm et al (2018) who have investigated how teams evolve, building on Tuckman’s (1965) influential model for team development, and claim that a “work group becomes a team when shared goals are established, and effective methods to accomplish those goals are in place... members feel involved and valued, and their work is of higher quality” (p.203).

In defining how to mark a group project, the first consideration is whether group dynamics, or group performance, are to be rewarded. This is the product vs process question. If group performance is key, then the individual contribution must somehow be evaluated. If the ability to work in a group is a learning outcome, then it has to be measured. Even after establishing the aim, the question remains how to allocate marks and how the marks should affect the overall grade. Winchester-Seeto (Winchester-Seeto, 2002) describes some strategies for mark allocation which are adapted and summarised here.

There are two main technological solutions relevant here: WebPA and SPARK. In WebPA, students receive a proportion of a group mark adjusted around a mean. SPARK allows for various calculations including a knee formula which does not reward those who do the bulk of the work but incentivises those who would otherwise underperform. Both of these systems invite students to provide a mark against a descriptor.

WebPA is a free, open-source, online peer assessment tool, developed by Loughborough University and appears to have become established as the current state of the art in peer-moderated marking. The development of the system is documented by Loddington et al (2009) and appears to have arisen in response to students’ sense of “unfairness” in receiving identical marks to their peers for group assignments. Key benefits are cited as reduced workload and time saving for academic staff, as well as a reduced number of complaints from students. Students also comment that the system facilitates more timely feedback and provides an opportunity to reward those who worked hard, while the most significant benefits for institutions are its flexibility and the centralisation of data (Murray and Boyd 2015, Honeycurch et al 2013). While these are undoubtedly key considerations, its creators recognise that collusion is a significant threat to the validity of assessment data in WebPA. This occurs when group members discuss and manipulate peer evaluation marks, rather than submitting independently and anonymously. The phenomenon was investigated by Pond et al (2007), who identified ways in which it might be detected, but providing such in order for institutions to take action might be very difficult.

Figure 2 Product vs. Process in Group Marking



AIM AND OBJECTIVES / RESEARCH QUESTION(S)

Ultimately, the School aims to create Engineers who will excel in team projects once employed in industry, especially with reference to the AHEP learning outcomes. By defining what characteristics these successful team players should exhibit, descriptors can be derived for the students to match to exhibited behaviour. Within this assessment context, the School also aims to identify and penalise students who make inadequate contributions whilst rewarding exceptional students whose contributions clearly exceed the overall performance of the team. In particular, we wish to nurture co-creation of output by teams rather than groups, to reward the sort of leadership which supports others in the team to achieve the technical learning outcomes as well as facilitating reflection and growth.

METHODOLOGICAL APPROACH

The study began with a literature search on approaches to marking of group projects (see also Lucas, 2017). By reviewing other methods, we decided to create a student-marked peer

evaluation of moderated criteria that reflects desirable characteristics of successful engineers.

Discussions with employers were conducted in order to establish desirable characteristics when considering employability, and to identify more subtle roles that aren't necessarily rewarded by students (Kao, 2013). These discussions were supplemented by researching competency-based recruitment and performance management of two companies: Jaguar Land Rover Ltd and BAE Systems.

Table 3 Business Behaviour in Industry

Jaguar Land Rover: Business Behaviours

- My Business
- Effective Relationships
- Strong Teams
- Efficient Delivery
- Agility and Flexibility
- Positive Impact
- Clear Direction
- High performance

BAE Systems

Continuously Improving

- Seeks and accepts feedback from others
- Can take a step back
- Considers how solutions / processes can be improved

Working Together

- Is willing to co-operate to achieve objectives
- Encourages others to become involved
- Actively seeks to understand others' point of view

The authors also worked together to identify characteristics of 'teams' separate to 'groups' to understand how team work might improve technical learning by all team members. By speaking with students who traditionally succeeded in the existing peer-review system, we were able to see that strong leaders were highly rewarded by their peers compared to those delivering work. This was particularly evident in multi-disciplinary projects where work was distributed according to skill (programming, manufacturing) rather than the amount of time the work might take. In order to enable team work, 'sprint' projects were introduced whereby students were co-located for a week-long project working on a task which required consideration of multiple approaches, negotiation, idea generation and evaluation. By

removing the luxury of time to ‘go away and think about it’ we were able to force groups through the stages of ‘norming, forming, storming and performing’ relatively quickly.

Figure 1 Group vs Team Characteristics

Group	Team
Separate goals, common interest	Common goal, separate skills
Strong leader bringing everyone’s contributions together	Share ownership
Individual accountability with one leader	Mutual accountability
Individual work-products	Collective work-product
Leader runs efficient meetings where work done is described	Open ended discussion and active problem solving during meetings
Proud of output	Proud of each other

We therefore identified four key skills that we believe to define successful team performance within Engineering:

1. Commitment: The team member attended meetings, provided ideas and was generally available as needed.
2. Performance: The team member contributed to their agreed role and to the success of the project as a whole.
3. Attitude: The team member was positive, honest and played a constructive role to identify and address challenges.
4. Team dynamics: The team member encouraged other members of the team, helped the group to reach consensus and did not engage in bullying or discrimination.

To facilitate peer assessment, a bespoke system was developed in house. In our proposed peer assessment system, students rate their team members according to each of these skills

using qualitative descriptors rather than a numeric score (see example in Table 4). We remove numeric scores to encourage students to focus on the evaluation criteria rather than the final numeric score. Success against the normal marking scale (1st, 2.i, 2.ii, 3, fail) is linked to a numeric scale ‘behind the scenes’. The highest scores were retained for students who not only showed high individual performance, but also facilitated achievement by other students. The four skills are weighted evenly, except for “Performance” with a double weighting. Students can write brief statements about each team member to support their chosen descriptors. Students have multiple opportunities to complete the review and receive feedback, encouraging improvement during the project.

The final peer score is calculated as follows. The scores assigned by a given student are normalised by the *median* of those scores. Using the median enables a student to recognise and reward exceptionally high performance, or call out absent members, without being forced to redistribute marks. After the scores assigned by each student are normalised, an individual’s final peer score is the mean of the normalised scores assigned to them by their teammates. The final peer score is then used to scale the group project mark to determine the individual project mark.

Table 4 Rubric for individual key skills

Key skill	Fail	2:2	2:1	1st
Commitment	Did not attend meetings and had no valid excuse	Attended meetings but was ill prepared and/or late	Well prepared for meetings, arrived on time and fully participated	Well prepared for meetings, arrived on time and encouraged others to participate
Performance	Does not contribute or perform well in the project	Is a good performer with effort varying throughout the project	Makes a sustained effort performing highly throughout the project	Holds others accountable and makes a huge effort with high performance throughout
Attitude	Did not contribute positively to challenges perhaps giving up	Morale affected by challenge but willing to persevere	Responded positively to challenge, accepting new direction	Aided discussion on overcoming challenges
Team Dynamics:	Is not transparent or willing about issues affecting the team and/or avoids or actively seeks conflict	Is not always forthcoming when discussing issues affecting the team and/or finds it difficult to negotiate	Is willing, fair and transparent when engaging with and negotiating team issues	Is skilled at identifying and bringing issues to discussion, negotiating and incorporating others’ viewpoints

KEY FINDINGS

We ran a pilot using a one-week project which is part of a module taken by all first-year engineering students (Systems Modelling and Computation). The results from the pilot system were compared with the existing system using a student survey. The students were

positive about the new system and liked the preliminary assessment which gave them a chance to improve before the final peer assessment. The use of feed-forward assessment in this way contributed to improvement in students' group-work skills.

We also compared individual student scores on group projects to their overall performance on other modules. We observed that the existing peer assessment system tends to result in higher comparative scores for lower-performing students and vice-versa. The piloted peer assessment system produces scores that are more reflective of the other assessments. This suggests that the proposed system more accurately and fairly reflects students' contributions.

There is a planned full trial of the proposed system in July 2019 to confirm whether:

1. Teamwork skills improve – by testing the same cohort again in a second year project we can evaluate the benefit of feedforward for group-work skills
2. Technical skills improve – by comparing the scores of high-performing teams with their individual score on the written examination we can see if teamwork improves technical learning for all team members. Conversely, we are interested in whether low performing teams have individuals with higher technical competence as measured by the written examination
3. Fairness – by observing group work in sprint sessions do academic assessors notice anything which is not captured by the proposed descriptors.

DISCUSSION

Group-work can undoubtedly be efficient for both academics and for students; large projects can be divided into smaller tasks yet a single output can be marked reducing workload for all. The authors wonder however whether there is an impact on individual learning, whereas in industry one would not expect the team to understand all components there is a requirement for students to demonstrate technical learning outcomes. We propose that there is a way to get the benefits of economy in group work whilst still ensuring learning across the group by promoting team-work. This also encourages a flexible workforce who are able to adapt to different job roles and learn from each other.

The literature reviewed identified concerns about student gaming which were evident in our own system. The well-accepted peer review system used in the sector had not addressed these concerns and, despite increasing diversity, the experience of individuals with diverse

needs of group work and assessment is not well-understood. It was clear that confident leaders were encouraged and rewarded by the existing system.

This project was motivated by the industrial experience of the authors which was at tension with the widely accepted system of peer-assessment within and outside of engineering. In particular, the business behaviours so encouraged and rewarded in industry were not rewarded or trained in undergraduate Engineers and, conversely, those encouraged and rewarded by the peer review system were not those desired by companies. The development of descriptors for both successful teams and for successful individuals did not therefore stem from the literature but from discussion with employers as well as brainstorming by authors experienced in both sides. This proposal sits at an unusual boundary between the two and is a perspective with further potential. By more closely aligning assessed behaviour in group-projects with those in industry we aim to improve students' success at assessment centres. This also gives students an opportunity to understand how they might be judged against set competencies (for example when attempting to gain chartered status) rather than specific achievement.

CONCLUSIONS & RECOMMENDATIONS

It is clear that there is merit to further explore the descriptors for desirable behaviour and to validate our initial findings that the sector needs more 'players' rather than 'leaders'. Discussion with a wider range of employers and academics would add valuable dimensions and help us to refine the criteria, especially when incorporating the descriptors for chartered engineers. Together with further refinement of the mechanism for weighting individual scores, the authors will continue to iterate and improve this peer review system whilst also monitoring longitudinally the benefit to students and their group work skills, perhaps measured by their success at graduate assessment centres or by improvements in their peer review scores. Iterations will also be monitored for the protection they offer against collusion and gaming to continue to improve fairness and accuracy in measurement of individuals working together in projects.

There are two follow-on projects which emerge from this work. The first is to look at how we can encourage and teach team-work as separate from group-work. Agile, co-located, multi-functional project teams are becoming more prevalent in Engineering industry with the advance of Scrum and Kanban methodologies not covered here. The authors will be teaching these methods to a subset of the Engineering cohort at the end of year 2 and wish to compare the experience of students once they have been taught how to work as a team.

Finally, the authors hope to gain deeper understanding of how individuals with varying needs and background experience group projects. We want to determine which factors affect the peer-scores as it is possible that students from certain backgrounds are unfairly penalised. We want to uncover the impact of bias and build a peer review system which prepares Engineers for working in ever more diverse teams and ensures all strengths are recognised by our own academic systems.

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Paper 4: Students' Perceptions of Individual and Group Performance in Capstone Projects

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ABSTRACT

Final-year capstone design projects in the Bachelor of Engineering and Bachelor of Software Engineering degree programs at the Australian National University (ANU) incorporate a student partnership model called the *Many Eyes* feedback process. This process has been successful in delivering real learning value to students and enabling students to deliver real value to clients by balancing project outcomes and good governance. This paper examines student's perceptions of the value their team delivered to the client, and the value they personally delivered. We discuss how variations here can reveal aspects of team function and dysfunction.

INTRODUCTION

Final-year capstone design projects are ubiquitous in undergraduate engineering degrees and provide an important opportunity for students to practice the skills of 'real'

engineering. Much of the learning experience in engineering degrees focuses on a student's ability to apply engineering science theory to solve relatively clearly defined technical problems. In contrast, in capstone projects, students encounter loosely defined real-world problems with real clients. As such, capstone projects provide a transitional experience that helps students become practising engineers (Trevelyan, 2015).

Curriculum approaches and assessment in capstone projects tend to emphasise either product or process. In our experience, a focus on one of these at the expense of the other fails to deliver real value to the students (i.e. the project team), the client, and other stakeholders, and does not prepare students for the creativity required to be valued graduate engineers. At the Australian National University Project students in the Bachelor of Engineering and Bachelor of Software Engineering learn in their capstone projects to balance the production of outputs and the processes required to create those outputs. A framework of 'delivering value' is used to discuss the quality of outputs and process through three iterations of a plan-act-reflect action learning cycle (O'Brien, 1998), facilitated by Project Audits that include an extensive feedback process known as "Many Eyes" feedback.

This successful approach to project-based learning described above has emerged over many years of continuous improvement in the Many Eyes feedback process and the adoption of the plan-act-reflect course structure. Building on the success of this approach, we are preparing to expand the approach to group projects in earlier years of the degree.

LITERATURE REVIEW / RATIONALE

Higher Education institutions, industry and accrediting bodies e.g. ABET in the USA, Engineers Australia (EA), and the Engineering Council in the UK, all consider capstone projects very important when preparing students for professional employment (Dutson, 1997; McKenzie, 2004; Todd, 1995; Trevelyan, 2015). However, there are challenges in the design of capstone projects, with emphasis on factors such as a focus on theoretical or practical outcomes, working with real-world clients or hypothetical clients, team size and moderation of team members within teams, evaluating different types of projects within a common framework, and an emphasis on project outputs or processes.

Regardless of these factors, capstone projects are considered a useful step in the transition towards becoming a practicing engineer. Capstone projects help students move from a

position of “customer” in an education experience, where the objective is learning and acquiring skills, to taking on the professional perspective of an engineer as a semi-autonomous active problem-solver. Further, each student comes to a capstone project with a different set of knowledge, experience and level of competency. This is especially true where project team membership is drawn from students in different majors, as they are at ANU.

The practice of engineering is to be comfortable enough with uncertainty to effect the best possible change using available resources (Koen, 2003). It is clear there is no ‘one way’ for an engineering project problem to be solved, and indeed no one way of arriving at that solution. In fact, focussing on either the outputs of the project at the expense of the processes (or vice-versa) can limit the deep and transformational learning that occurs when students successfully navigate the engineering problem space (Gardner and Willey, 2012).

It is important that students grasp the idea that, no matter what, a design can always be improved, and iteration allows the engineer to learn quickly. This is often addressed in the field by iteration through a design cycle, such as plan-do-study-act (Deming, 2000) or think-make-improve (Martinez & Stager, 2013).

In semester-long projects, the timeframes required to iterate whilst using traditional, document-based engineering processes can be cumbersome and ineffective. Recent developments in the innovation community, such as lean startup methodology (Ries, 2011), emphasise the importance of focussing on ‘value’, evidenced in the proliferation of canvas tools such as the *Value Proposition Canvas* (Osterwalder, et al., 2014). In these frameworks, activities are prioritised towards understanding how to deliver value to a client using the expertise and services of the team.

Considering these factors, and the fact that students themselves vary in skillset for a given problem, it is challenging for the educator to be prescriptive in either ‘how’ the project is to be done or ‘what’ the project will deliver. What the educator can do, however, is guide the student as to ‘why’ the planning, execution and reflection on activities to do with both aspects is an important part of the transition to becoming an autonomous engineer.

AIM AND OBJECTIVES / RESEARCH QUESTION(S)

In this paper we explain the use of an audit and feedback process that supports students as they develop their awareness of and ability to create value through engineering design projects. These activities support the development of students' awareness of their engineering skills and qualities and their acquisition of an engineering identity.

In this paper, we investigate how the concept of value is being used to frame and evaluate team and individual performance within an engineering capstone project course. In particular, we examine the students' perception of the difference between the value that the individual has delivered to the team in contrast with the value that the team has delivered to the client. By exploring this difference, we seek to understand the dynamics of teams so that we can in turn support students to improve their learning throughout the project.

THE ENGINEERING EDUCATION PROBLEM AND INTERVENTION

At the Australian National University a capstone project has been an important part of the final-year of the engineering program for more than two decades. However, students and graduate employers regularly provided feedback that students were not well prepared for the 'real' engineering work they would encounter as graduates. At the time, projects were inspired by real projects, but operated in a sandbox environment, where the primary objective was to provide a safe space to apply the engineering knowledge students had acquired throughout their degree, rather than exposing students to the vagaries of authentic practice. Most importantly, there was consistent feedback from students that the emphasis of the project was on 'teamwork' and 'documentation', rather than actually implementing or building the design. The course description, approved several years before the process described here was implemented, echoes this sentiment:

This course is designed to mimic an industrial design problem as closely as practical in a university setting. Students are assigned to teams and given an ill-defined problem statement. From the problem statement, the students are responsible for developing the full set of requirements and key performance indicators to guide the design. The students then proceed through a systems design process including conceptual design, sub-system requirements, and quantitative tradeoff analyses, using the full range of engineering science and professional skills developed during

the degree course. The course emphasises teamwork (both team leadership and membership), communication skills (formal and informal, written and oral), and team and personal management and a professional approach to engineering design. (ANU, 2014)

If design is a process of learning through a design cycle, then, as shown above, students in the previous version of the course did not get the opportunity to cycle through the entire design cycle and learn by challenging the assumptions they had made in earlier phases. In final design presentations to clients, it was common to see a project team to a client learn that the project report they had delivered after a semester of work had made a series of incorrect assumptions at some point in the project planning, leaving the project outcomes irrelevant or out of date.

Because the project timeline did not encourage iteration, or indeed even mention it, students frequently left the project with misconceptions about the nature of engineering project work. For example, as suggested by the process described in the course description, many thought that engineering projects are linear. In practice, however, a project is dynamic: even the process of establishing requirements is an iterative process, as the project stakeholders move to a deeper understanding of the technical requirements, or as the external environment around the project changes: in practice it is rare for requirements to be set once in a project and never revisited (Robertson, 1998). However, because students were not iterating through a design-cycle, they did not get the opportunity, for example, to learn that their requirements were untestable, or that their requirements specification was ambiguous.

There were also challenges in differentiating the contribution of individuals within a team, especially where team size varied between 10 and 20 people. With such large teams, hierarchical structures typically emerged, and it became apparent that team members in leadership roles would routinely be awarded higher marks than team members left to do the detailed engineering work. There was an overwhelming perception that teams contained freeloaders, and a belief that most team members were above average. Because of the absence of a framework that differentiated the value contributed by individuals within the team, the course would routinely disadvantage students who were less forthright in establishing a leadership role early in the project. This tended to allow domestic male students to dominate.

The intervention for the Engineering Capstone Project course described in this paper came in 2017, when a new convener was prompted to address these areas of feedback. As a result, the course was aligned with a similar course in the Research School of Computer Science, which had a track record of successfully running teams of 6-8 software engineers in projects with real-world clients, where the focus of the course was assisting students to become autonomous in their delivery of project value to the client (Johns-Boast and Flint, 2013).

A Focus on Value

Aligning the Engineering and Software Engineering courses required the formalisation of many implicit processes, and the balancing of many conflicting ideologies. For example, both engineering and software engineering faculty believing in taking a 'systems approach' to design, however different approaches to teaching this had developed because practices in the engineering profession are more document-centric while practices in software engineering tend to be more development-centric.

Further, project clients came from a range of industries, and each had their own internal processes that they followed to undertake their projects. For this reason, the Software Engineering course used the rhetoric of doing what is valuable for the client, with the belief that if the team did what made sense in the context of the client's processes, then this would lead to better outcomes for the client. In the new aligned courses, this rhetoric is represented in advice in the course material such as:

*Everything you do in your project should deliver value to yourself, your team or your client. If you find yourselves doing something that does not appear to be a good use of time, or seems unnecessary, then **STOP** and **REFLECT** - do you really need what you are doing, have you missed something, can you use your time better?*

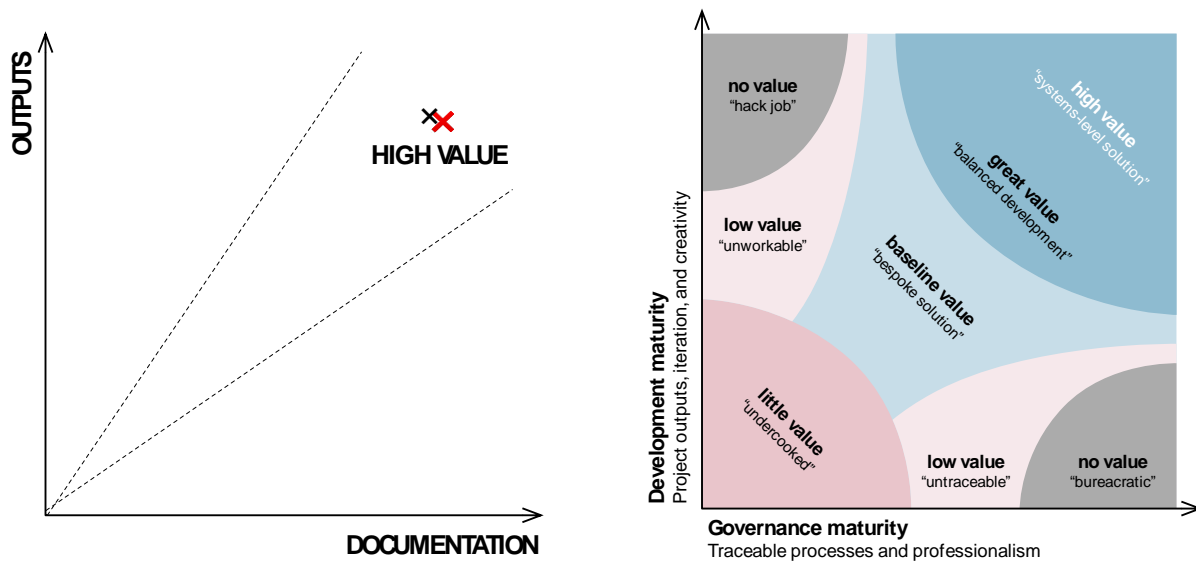
We do not talk about 'marks'. If you are using language such as 'marks', 'grades', 'scores', or 'points', you are missing the point. Instead, focus on how your work will be 'evaluated' - the value you are generating for your client. (Browne and Flint, 2017)

The software engineering academics' approach to thinking about value as the balance between project outputs and governance evolved over a number of years. However, this approach was an adjustment for the Engineering cohort, and required additional discussions, and a concerted effort to make the principles explicit for students. This often resulted in a discussion with the project team about value around a graphic similar to Figure

1a. Subsequently, the Engineering course has developed this concept further, with a formalisation of zones within the axes which appears in the course guide (Browne, 2018), shown in Figure 1b. This description of value provides a common framework for students to judge the quality of the value they are delivering through identifying their position on the value graph.

Figure 1: Value graph used to communicate need to balance project outcomes with good governance to students.

a) left, a depiction of the original conceptualisation; b) right, the current version



The Value of Many Eyes

Value is a relative idea, and different members of the project team are likely to have different perspectives on where they sit on the value graph. Similarly, the team is likely to have a different perspective from the client, which is likely to be different from the teaching team's perspective. Engineering necessarily deals with multiple criteria of correctness. This point can be missed within the education system in which students have been enculturated: the standard academic practice of giving students a single grade that summarises their achievement in a subject gives the misleading impression that a single dimension of "goodness" exists. In order to prepare students to perform as professional engineers they need to become comfortable with negotiating multidimensional criteria of quality.

In order to help students understand how their work correlates with the value graph, we have introduced a 360-degree feedback process that incorporates the opinions of 'Many Eyes'. This occurs in three audits through the semester. In addition from self and peer reflection from group members, students receive rich qualitative feedback from teaching staff, clients, and a second student project group, which we refer to as the 'shadows'. We help students to understand that this is all useful information, and that they need to take the information and form their own judgement about how the project is going and how to improve.

To demonstrate the richness of this process, example comments from a team's project audit are shown below from each of the Many Eyes' perspectives. As can be seen, the self-evaluation is quite positive, but the peer, tutor and client feedback provide alternative perspectives and emphases, complementing the team's perspective.

Self-evaluation on Decision-Making

"The team is effectively managing the team meetings and documenting the key decisions and changes through a change log. The team is also having meetings with the client and [sic] every week and with the client and documenting the outputs from the meetings."

Peer feedback on Decision-Making

"The team has clearly settled better into their roles since the first audit. [The] detailed decision tracking documents are very helpful [... but the] decision making log and to-do list [are] clearly not being used regularly and [are] only updated just before audit week by select members of the team - seems a little bit dishonest. [Some documents are] empty."

Tutor feedback on Things to be Improved:

"I can see that you have acted on feedback to make an increased effort to document the system requirements and your design (e.g. Systems architecture diagram). This is important to be able to effectively hand the project over to future teams. Keep going with this effort."

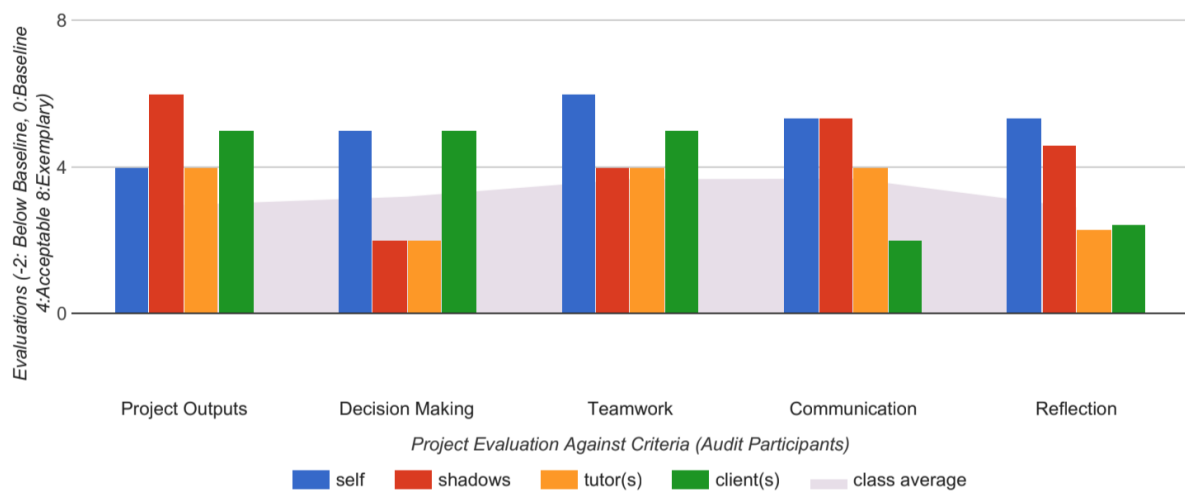
Client feedback on Things to be Improved:

"Follow through on providing promised documents and other items following meetings could be improved. Nothing major has been missed yet, but I would like to keep the documents on hand for our records."

We take the perspective that regular formative feedback is necessary to enable continuous improvement and the development of professional judgement. However continuous assessment can have negative consequences, such as inducing a fatalistic response if early results are poor, and making students risk-averse. An attitude of “fail early, fail often, and fail forward” can encourage a more ambitious approach to the projects.

Students also receive quantitative progress indicators (Robertson, 1988) at each audit, based on Likert-scale evaluations from the teaching staff, clients, self and peers. These indicators help students to frame the comments in their feedback. These indicators are separate from grades, but help to inform the team how the Many Eyes perceive they are performing, and how that relates to other teams in the course. The graphic that students receive as part of the feedback is shown in Figure 2. A common observation is that one stakeholder will have a different perspective from others; for example, a client identifying communication lower is usually a subtle reminder to the team to meet with the client regularly.

Figure 2: An example representation of quantitative project indicators across the Many Eyes. Note that the criteria Decision-Making, Teamwork, Communication and Reflection all relate to the ‘processes’ axis of the value graph. Shadows are the group of ‘peers’ auditing the project.

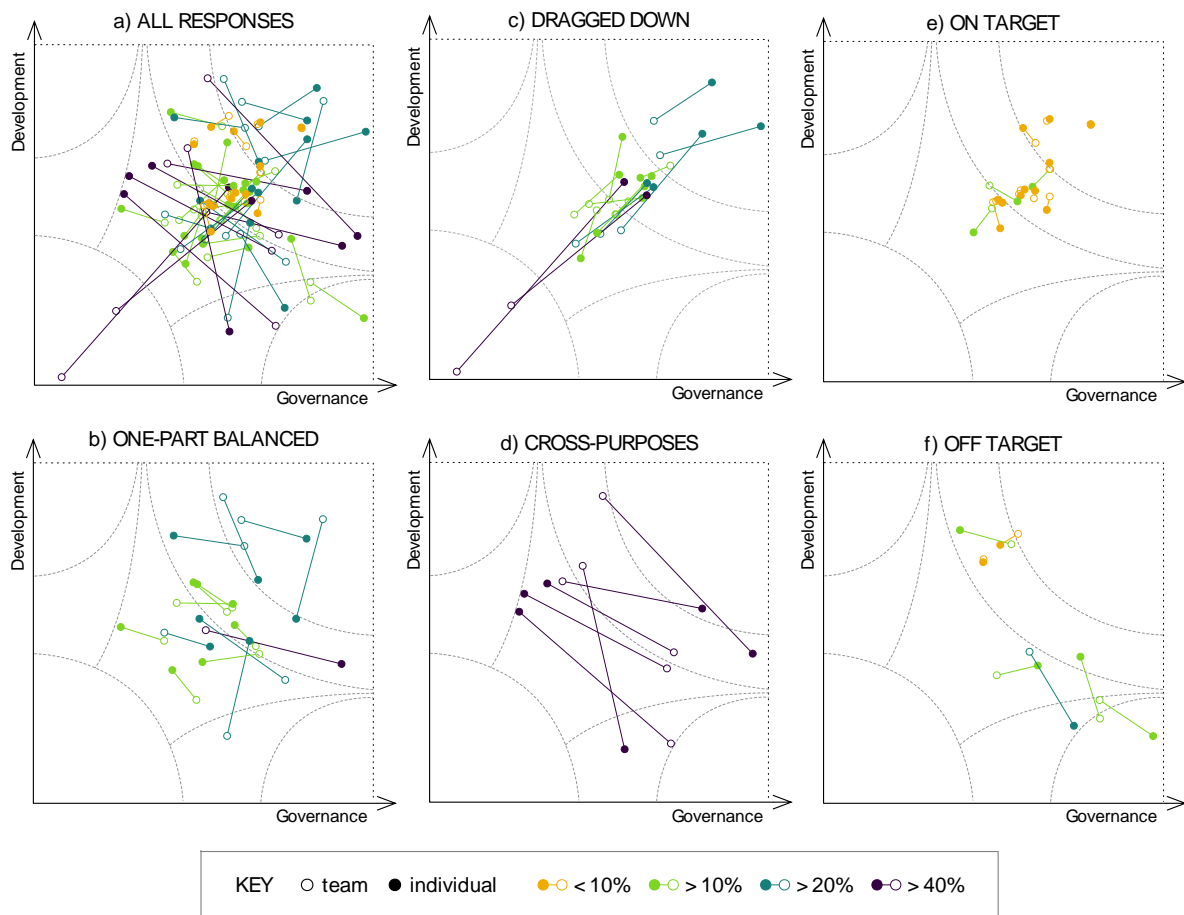


After each audit, teaching staff work with students to process the feedback and develop an action. At the beginning of the project, the focus on developing the plan is about learning quickly and moving forward. Towards the end of the project, the discussions about value moves towards handover of the project, and how the project will be of value when the team is no longer involved with it.

KEY FINDINGS

We surveyed students at the completion of their project to examine how students understand their value creation in their project teams and the contribution of the Many Eyes feedback process to developing their understanding. We were particularly interested to discover whether there was a difference in the perception of the contribution of the individual's value to the team's overall value, keeping in mind the issues around team member contribution highlighted in the previous version of the course.

Figure 3: Student perception of team and individual value delivered. Colour denotes percentage magnitude of the locations between perceived team and individual value relative to the size of the axes.



Students were asked “Where do you think the project value delivered is located on the Value Graph?”. Students positioned their perceived value to that the team provided to the client, and the individual provided to the team. Just under half of the class (57 students)

responded to the survey, given at the end of the semester. The results are shown in Figure 3, and the emergent categorisation of these results are shown in Table 1.

From these data, five distinct categories of team/individual perceptions emerged, shown in Table 1.

Table 1: The five emergent categories of team/individual perceptions

Category	Count (%)	Description
Part Balanced	15 (26.3%)	The team's value delivered is balanced, but the individual's value delivered is weighted towards one axis; or The individual's value delivered is balanced, but the team's value delivered is weighted towards one axis
Dragged Down	15 (26.3%)	Where the individual's value delivered is balanced, but the team's value delivered is lesser; or The team's value delivered is balanced, but the individual's value delivered is lesser
Cross Purposes	6 (10.5%)	The team's value delivered is weighted to one axis, but the individual's value delivered is weighted to the other
On Target	14 (24.6%)	The team and individual's value delivered are approximately the same, and balanced between the axes
Off Target	7 (12.3%)	The team and individual's value delivered are not within the 'balanced' area.

DISCUSSION

The five categories shown in the data demonstrate different aspects of team dynamics, and give insights into the way that teams consider the value they are delivering during the projects. It is uncertain whether categories demonstrate positive or negative team dynamics; however, we assume that a balanced position (towards the $x=y$ line) is more desirable than a position away from this line.

We hypothesise that the 'On Target' category demonstrates a preferred mode of healthy team dynamics, with team members pulling in the same direction as the team. The Part Balanced and Cross Purposes mode may also demonstrate healthy dynamics: a team with a make up of different skillsets may divide work differently. For example, a student good at detailed design work may be working towards the project output axis, whereas other members of the team may be complementing this by pulling towards the governance axis. In both of these categories, there is a mix between the individual or the team being the balancing factor.

The remaining categories are likely to highlight a more negative team dynamic. The Dragged Down category likely exhibits the perception by an individual that they were much more effective than their overall team in delivering value, with 12 of the 15 responses in that category orientated in that direction. This is an often-heard complaint from students who achieve high grades in more individualistic subjects. The Off Target category indicates a situation where a team and the individual are focussed too much on one area. This could likely be a function of team skillset, where all team members naturally have a tendency towards one axis. More positively, it could be a function of project scope, where the project requires a focus on one axis, such as a document-heavy project.

These five categories might also provide insights into the real-world dynamics of teamwork. The data, as collected, provides little insight into whether these dynamics are associated with positive or negative team dynamics. They are anonymous so it is not possible to compare the perceptions of the various team members. These are areas of future investigation.

However, what is known is that the nature of the engineering workforce is changing in the face of technological evolution. As this evolution continues, the opportunities for students to work on clearly defined 'sandboxed' problems becomes further disconnected from the reality of professional practice. A focus on value, delivered through a balance of process and outputs, creates a flexible and realistic operating space for effective project work, delivering value to students and industry partners. The 'Many Eyes' approach prompts students to engage with stakeholder perspectives, seek regular feedback and respond, and reflect on their own contributions. This process appears to encourage the development of engineering identity as they move into the profession.

Structured, anecdotal, and informal feedback to date indicates that students experience increased confidence that they have learned what they need to be employable as engineers and faculty are confident that students' practical engineering skills are enhanced. Industry

sponsors are particularly enthusiastic about the focus on delivering real value, with a consequence that we have many more projects than student teams each semester.

CONCLUSIONS & RECOMMENDATIONS

The concept of value provides a useful bridge between process and product in engineering projects. The 'Many Eyes' Process helps students to engage with many stakeholder perspectives and negotiate their understanding of their success in delivering value. With the demonstrated resonance of value as a concept for navigating how the teams approach their projects, we plan to incorporate the value graph evaluation into the project audit process, to allow for more direct dialogue between the students and the teaching team throughout the semester. This will give us a platform for discussing the ongoing team dynamics over the project life-cycle, and promote opportunities for targeted discussions to improve the dynamics as they arise.

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Paper 5: Students Perception Towards Using a Creativity Competition to Build-up Teamwork

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KEY WORDS: students, engineering, teamwork, collaborative

ABSTRACT

A focus group was carried out with students in the 3rd year of Mechanical Engineering, Computer Aided Design and Product Development Design undergraduate degrees, to test their perceptions of developing teamwork skills through participation in a simple creativity competition.

BACKGROUND / CONTEXT

Teaching approaches have a high impact on students' learning. Traditional approaches in engineering courses produce graduates with high technical ability and, in the majority of cases, teamwork and communication skills are either limited or neglected (Kamarudin et al, 2012, Halizab and Zuwawi, 2015). For this reason, engineering courses should be revised and modified to incorporate learning and design techniques, where communication skills are essential in developing strong working relationships and achieving operational goals. Skills, such as critical thinking, collaborative skills, connectivity and creativity, are essential and must be developed by students in the higher education (Breivik, 2005), with research finding that these skills can be enhanced by undertaking teamwork activities.

Unfortunately, the majority of the academics in the area of engineering tend to be appointed focused on knowledge, research capabilities and number of publications, rather than on the ability to teach and pedagogic practices (Kamarudin et.al, 2012). As engineering educators, we need to produce graduates that are capable of solving problems and we need to enhance and promote teamwork, creativity and critical thinking among other skills. As an example of how to enhance these skills, a creativity competition was introduced to a

multidisciplinary third year module at undergraduate level which involved Mechanical Engineering, Computer Aided Design (CAD) and Product Development Design (PDD) students. To evaluate their perceptions towards the activity, 8 students with differing demographic backgrounds, such as age, potential future career and student origin, i.e. home student, EU or international, were invited to participate in a focus group.

Questions in the focus group followed the AIDA Model of Information Processing (i.e. Awareness, Interest, Desire and Action) and a qualitative approach was used to analyse the results. The most significant finding was that, in general, mature students were able to perceive the benefit of the competition to build teamwork skills, whilst younger students focused on the fact that the competition did not reflect individual capabilities. They also did not take the opportunity to challenge themselves, in terms of their project management and communication.

LITERATURE REVIEW / RATIONALE

The purpose of this research is to provide students a relaxing and fun task to explore their creativity and built their team-workability to build a strong relationship for future complex work assessment as part of the module.

For a team to be effective, not only are communication and social skills required but motivation and the ability to develop trust are also essential (Sharma and Mishra, 2009). To demonstrate this, Gilbert et al, (2017) listed the soft skills required by scientists and engineers to promote teamwork, with moral trust, emotional intelligence and strategic thinking highlighted as the most important skills for effective collaboration in a research team.

However, the focus on 'soft skills' pre-dates the 21st century – accreditation criteria, for engineering programmes in the United States, specified the inclusion of not only a 'broad education necessary to understand the impact of engineering solutions in a global and societal context but also the 'ability to function on multi-disciplinary teams' (Vanasupa et al, 2009). Developing this theme, these authors developed a Four-Domain Diagram, which included both left-brain associated (cognitive and psychomotor functions) and right-brain associated factors (social and affective functions), which, they posit, combine to stimulate student interest, autonomy and perceptions of overall value of an activity. On applying this model to engineering, the factors translate to systems thinking, understanding, engagement / active learning and moral / ethical development (ibid), which, the authors specify, correlate to student perceptions of relatedness and mastery, which, in turn, are positively correlated with motivation.

They do warn, however, of the need for ‘sufficient instructor support’ or ‘scaffolding’ for the learning process, both in terms of the academic content and also the management of the group process. Where these are not perceived as adequate, they found that the impact of the group learning process was reduced (ibid, 2009).

Additionally, Nisbet et al (2016) identified a gender difference in initial group-participation roles. They found that equal-gender inclusion, both in courses and group-work, had a significantly positive impact on the experience in both, with males, initially, recognising that female group members rendered the process more efficient and managed. However, this study identified that this impact was transitory and, by the second trimester of the study, female participants not as eager to undertake heavier group roles, thereby engendering, in participants, a more equal attitude towards gender inclusivity and balance.

It is evident, then, that incorporating group-work, involving diverse teams, in engineering education can assist students in developing a wide range of skills, which are not limited to the activities which are incorporated. However, Gross et al (2018) highlight that ‘their success may not be a one-size fits all’ approach – these authors refer to previous experiences influencing participants’ perceptions, whereas Lee et al (2018) introduce the notion of Emotional Intelligence (EI), which, they state, is strongly correlated with teamwork skills. The competencies they cite as components of EI are self-awareness, self-regulation, motivation, empathy and social skills, which reinforces the factors involved in the Vanasupa et al 2009 study. However, Lee et al (2018) recognise that ‘empathy and interpersonal interactions are not conventional topics in most STEM undergraduate’ programmes and they recommend further investigation to address this deficiency.

Overall, then, inclusion of team-work activities appears to be a highly topical subject in engineering education, with the effects, where positive, being wide-ranging, with benefits outwith the academic realm. However, in order to be effective, instructor input, to both content and group-work procedure, appears to be the extremely influential.

AIM AND OBJECTIVES / RESEARCH QUESTION(S)

This study aimed to:

- Establish baseline perceptions of teamwork, communication and creativity in target group
- Determine gaps identified in current capability levels
- Assess impact of initiative in which students participated
- Determine influence of this activity on future practices
- Assess influence of gender stereotypes in operation, if applicable

- Identify any cultural differences in all of the above

METHODOLOGICAL APPROACH

In the module activity, students were encouraged to participate in multidisciplinary teams of 6, in order to conduct the creativity activity. Students selected an egg drop challenge, where sustainability, volume, mass and creativity were the main parameters to consider. The activity also included the development of a poster with the purpose to demonstrate communication skills by inviting the university community to attend the challenge.

To evaluate perceptions of the overall activity, a focus group of 8 students, including different ages and nationalities, was conducted in order to obtain and compare their perception towards teamwork and if the selected activity which was considered a simple and fun task could help them build and enhance their team relationship for future teamwork in more complex activities.

Table 1 shows participants' demographic details. The session lasted around one hour, which commenced with a set of projective techniques (Appendix). Questions were structured around the basic communication Model AIDA (Awareness, Interest, Desire and Action) and data was analysed using Thematic Analysis.

Table 1. Demographic details of participants in the focus group

	Age	Gender	Nationality	Degree
1	31	M	Scottish	Mech Eng
2	20	F	Danish	Mech Eng
3	20	M	Scottish	Mech Eng
4	20	F	French	Mech Eng
5	27	F	Scottish	CAD
6	40	F	British	CAD
7	30	M	Scottish	CAD
8	21	F	Spanish	Product Design

This represents a qualitative approach, which involves questioning *knowledgeable* respondents individually, or in small groups, regarding the '**why**' of behaviour. However, whilst this type of research is very interesting, the main limitations should be considered; i.e.

a) the comparatively small number of respondents involved

Participants are selected to take part on the basis of their attitudes or behaviour, in order that both can be probed. However, only a small number will do so, thereby representing a large class – but this is justified, due to the deep probing that qualitative techniques allow;

b) the high degree of subjectivity

There is no way to separate the researcher from the research – and as the researcher is also an employee in the university, the potential for bias is high. However, this can be controlled, to a certain extent, by making use of a structured set of questions and by recording interviews.

Thus, whilst the findings are of great interest, care should be taken if the findings are to be projected to a wider group.

KEY FINDINGS

- The majority of the students felt that teamwork was extremely important but, at university level, it can be a highly problematic as not all members make the same effort
“Group assessment may be unfair as not all team members put in equal effort to the project”
- A distinction was made between younger and mature students, with older students feeling that they have to ‘take charge’ and manage the process, with the younger participants agreeing that this tended to happen
“I lost my temper in the end with some of the team and told them that they should just get on with it”
- The majority of groups worked in a collegiate and democratic fashion, giving each team member their say, ignoring those suggestions with no valid justification
“We did it as a group – but some of the team were not of the right mind-set, just suggesting things with no backing or evidence to justify it”
- All participants were aware of the need for effective communication skills, as well as those of time management and organisation
“You can be the brightest person around – if you can’t communicate, you won’t go far”
- The majority of the students felt that teamwork is not something that can be taught – they perceived that only experience creates that skill
“Teamwork is not something you can teach – managing that process only comes with experience”

DISCUSSION

Despite students being encouraged to build multidisciplinary groups with the purpose of having different points of views due to different degree backgrounds, students preferred not to take this advice, choosing to work within their common timetable. This meant that students within the same degree would be on campus at the same time. Only 2 groups out of the 12 groups were formed with members from the three disciplines and these were formed by Erasmus students living in the same accommodation. Results showed that these groups, formed by French, Spanish and German students, aged 20-22, performed better regarding final project outputs and communication skills, not only on the creativity competition but also in the more complex activities scheduled later on in the term. They also indicated that they were satisfied with the whole experience; i.e.

"I really enjoyed it – it was challenging and intellectually stimulating"

It did appear that, from the outset, participants attempted to work in a collegiate and democratic fashion, giving each team member their say. However, students highlighted that some members of the group simply made suggestions, without providing any justification, and these were ignored. 9 out of 12 groups that were consolidated established regular meetings where ideas provided by each member were analysed before a decision was made; i.e.

"It was fun and I was able to work out how to get my team meshing well together so that we can be a well-oiled machine for future projects. Really worthwhile"

Despite the easy task involved for the creativity competition, in order to build-up teamwork, it was observed that 7 out of the 12 groups took an easy route and delivered a product which was not reflective of the skills of a level 9 student (Level 9 in Scotland is equivalent to level 6 in England). They replicated past activity / experience, rather than applying engineering knowledge. However, the remaining groups (5) did make calculations and created different prototypes. CAD and PDD students described the activity as challenging due to the calculations involved but they did feel that this was achievable.

"It was interesting to apply knowledge from the engineering field for calculations to apply formulas, materials and thinking about the way a real product would be developed in real life"

The main reason that creativity suffered in 7 out of the 12 groups was because of the lack of input from all group members and the prevailing attitude was just to 'get the project done on time' and this approach was more prevalent in groups formed with 100% young members.

4 out of 12 groups had a team member with a dominant personality who acted as the 'leader' and seemed to make decisions autonomously. Because of this, a good idea could

be rejected, with the individual who generated it receiving no credit as the group chose not to take it forward. This issue caused friction between group members, especially the young students, who preferred to step back and make no contribution; i.e.

“Communication between group members was not always the best for making important decisions using Facebook - sometimes there were long response times”

7 out of 12 groups with a mix of mature and young students struggled to communicate and make decisions. 49 students of 82 (60%) mentioned that from this first group exercise, they learned a lot in terms of managing the group dynamic and assessing the strengths and weaknesses of fellow students, with this information being used when making choices of groups to join for the next teamwork assessment. However only 25 of the students (30%) mentioned that they were happy with their teamwork, indicating that they were able to solve their communication problems, resulting in them continuing to work together for future assessments; i.e.

“It was great fun and a good starting point to start working as part of a team”

10 out of 12 mature students perceived the task as a good way to build-up teamwork as it was a fun activity and an opportunity to understand the dynamic of the group. It must be highlighted that 25 of the students (30%) were involved in a similar task in primary school, and 20 out of these 25 students repeated the same product as was delivered during their primary studies rather than challenging themselves to apply all the knowledge gained along three years of study. By comparison, 57 students out of the 82 were undertaking the task for the first time and they did apply engineering concepts.

CONCLUSIONS & RECOMMENDATIONS

- The creativity competition approach was better than ‘chalk and talk’, as students felt it provided an opportunity to be creative and to ‘see how ideas can work in practice’.
- 10 out of the 12 groups agreed that the easy task assigned allowed students to work in a more relaxing environment, improving teamwork ability.
- If the groups had worked well, teamwork would have led to a better project but, where difficulties arose, this impacted on the overall performance.
- The majority of the students mentioned that “teamwork is not something you can teach – managing that process only comes with experience” so, with a view to future recommendations, it is clear that it is important to provide students

with advice not only on teamwork but also on how to manage conflict in order to enjoy the teamwork experience

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APPENDIX

Questions set-up for the focus group following AIDA approach

Awareness

So, generally, how do you feel about teamwork? Experiences?
Communication – is that important in your future degree area? In what way?
Creativity – is that important? How / in what way?
Do you think that those are graduate attributes for your industry? In what way?
Tell me about the challenges involved in creativity Competition
Had you done this challenge before? How did you feel about it?
So how did you change it for 2018?
Did you see how your development would benefit from it? In what way?

Interest

How were your groups formed? Did you consider cross-disciplinary groups?
Self-Directed Learning – so how did you start the task off? Individually or as a group?
What worked well?
What would you change?
Did you learn anything from it?

Desire

Problem-Solving / Decision making – what happened when you had group discussion?
Did this lead to better results?
Or would you rather have done this on your own?
Overall, did this stage improve the process / outcome? In what way?

Action

Final result: how did it all work out?
How do you feel about your teamwork skills, now that it's over? Have they changed in any way?
Your communication skills?
How do you feel you learned from this task? Better than chalk and talk?
Would you recommend it to other lecturers / modules? What would you say?

Paper 6: The development of a psychometric test aimed at aligning students to a range of professional roles

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KEY WORDS: Graduate, competence, skills, engineering

ABSTRACT

Dublin Institute of Technology (DIT), working as part of the PREFER project, a European commission funded project, have developed a psychometric test in order to better align engineering students to three distinct professional roles within industry. This paper reports on the development process of the test, which took place between February and August of 2018.

BACKGROUND / CONTEXT

The PREFER psychometric test consists of two parts: a motivation questionnaire and a competence test. In the motivation questionnaire, students were asked to indicate their preferred course of action on a particular item from a list of 3 responses. Each course of action was aligned to one of the three professional roles within the PREFER professional roles framework as illustrated in figure 1.

Figure 1. The model of professional roles utilised in the PREFER project



The main objective of the questionnaire was to familiarize participants with the model and raise awareness about the variety of engineering functions an engineer fulfils. It was operationalised as a questionnaire to assess a participant's motivation to complete certain tasks and one major advantage of this format was that the keying process was quite straightforward, making it much easier to map a particular choice to a role. Another advantage of this approach was that the questionnaire required only a small amount of cognitive effort to complete. As students were subsequently asked to complete the competence test (a cognitively loaded test), it was desirable to keep cognitive load at a minimum in the motivation test.

The competence test was developed as a Situational Judgement Test (SJT) to assess how a participant distinguishes appropriate responses from inappropriate responses to a particular dialogue between 2 actors. These dialogues represented realistic engineering scenarios drawn from multiple interviews with practicing engineers, in the next phase of the research the test will undergo a rigorous face validation drawing on the methods proposed by Nevo (Nevo, 1985). The objective of the competence test was to evaluate a students' fit to a particular professional role based on the ratings they provide to each of the responses on a particular item. This was achieved by developing the test items around the competences collected from the expert panels. A measurement of role fit rather than competence fit was chosen because measurement of competence fit would have required a large number of observations per competence for a reliable measurement. Looking for a role fit allowed 23

competences to be measured and used as indicators of the role fit such that the construct under examination was the role, not the individual competences.

LITERATURE REVIEW / RATIONALE

In 2014, a study into the labour markets of Europe revealed that a large number of European countries encounter difficulties when recruiting STEM skilled labour. Looking at past, current and future trends, the study identified a number of occupations in Ireland as mismatch priority occupations. An occupational mismatch occurs when there are more job vacancies than individuals who meet the criteria to fulfil the role. Following an assessment of Irish labour markets, engineering professionals and technicians were identified as a sector with a high degree of occupational mismatch (*EU Skills Panorama*, 2014). The report suggests that at a European level:

"There are emerging skills shortages, skills gaps and recruitment difficulties . . . These include the need to combine the STEM skills of graduates with the 'soft' employability skills as communication skills, team working and creative thinking which help apply STEM skills in the business world and which are important to innovation " pg. 4

There is an ongoing shift in the labour market as industries moves away from traditional manufacturing and begin to take a larger stake in the services sector (Schettkat and Yocarini, 2003). This shift has resulted in companies and firms seeking out graduates who possess the transversal or professional skills required for success in these new roles. To this end, the PREFER project was established to identify the competences associated with the 3 professional roles as outlined by the PREFER model, to allow students to reflect on these roles and identify their relative strengths and weaknesses within a particular role and finally to develop unique curriculum elements to help train these competences.

AIM AND OBJECTIVES / RESEARCH QUESTION(S)

The PREFER psychometric test aims to evaluate participants' motivations to work in a particular professional role and to align each participant to one of the three roles based on 23 competence indicators. Moreover, the test will provide tailored feedback to the participant about their motivations and their fit to a particular professional role. Once the test has been placed through a full validation, it will be transformed into a pedagogical tool to give students a better sense of who they are as engineers and to allow them to reflect on the competences they require for success in the labour market.

METHODOLOGICAL APPROACH

Adopting the view that a unique set of competences can be attached to each of the three professional roles, a modified DELPHI study was carried out to gain industry's perspectives on the competences they deemed most important for each role. These competences and their definitions were drawn from Binder Dijker Otte's (BDO's) list of competences. The DELPHI method has proven a popular method in identifying core competences which are deemed important in a number of fields, including food safety undergraduates (Johnston *et al.*, 2014) audio engineering technology undergraduates (Tough, 2009) and management information systems graduates (Strnad, 2013). First, drawing data from the industry partners of the PREFER project in 3 expert panels with Electricity Supply Board International (ESBI) in Ireland, Siemens in the Netherlands and ENGIE in Belgium, whom all engage in similar economic activities, the study was expanded to include 9 additional expert panels which were conducted with an automation firm, a construction consultancy firm and a telecommunications firm. Several other companies and consultancies were also included, with variation in both firm size and economic activities to capture a wide cross section of perspectives from engineers across Ireland, Belgium and The Netherlands. (Craps *et al.*, 2018). In the final stage of the development process, the psychometric test items were brought back to ESBI, ENGIE & Siemens for their HR departments for further consideration and feedback.

DISCUSSION & FUTURE WORK

The next stage of the research involves establishing the face validity of the test items on the SJT. This will be achieved by triangulating the feedback provided by the HR representatives in ESBI, ENGIE & Siemens with the feedback from 3 expert panels of engineering academics. This research constitutes the face validation phase. Following on from this, the same items will be provided to practicing engineers to establish an expert scoring key to appropriately weight the responses to each of the items. After the face validation phase a pilot version of the SJT will be combined with the motivation test and piloted on a cohort of engineering students the data from which will form the basis of a concurrent validation study.

CONCLUSIONS & RECOMMENDATIONS

In conclusion, a vast amount of literature has explored the transversal skills required for an engineer to succeed in the labour market (Carthy, Gaughan and Bowe, 2018) but there is a scarcity of research regarding the types of roles that an engineer can fulfil after graduation (Craps *et al.*, 2017). It is therefore the aim of the PREFER project to fill this void in the literature and explore not only the roles available to new graduates but also to help students to develop the competences required to succeed in these roles.

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Paper 7: Teaching Professional skills in Engineering Programmes: The Academic's Perspective

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KEY WORDS: [Phenomenography, Approaches to Teaching, Professional Skills]

ABSTRACT

Engineering graduates in today's world face a global industry where professional skills are as important as the intellectual prowess gained by obtaining a degree itself. The importance of these skills is abundant in literature, yet so too is an ongoing barrage from industry that Higher Educational Institutions (HEIs) are not developing sufficient professional skills within students. This occurs against a background of accrediting bodies who have adopted programme outcomes, which require employability/professional skills to be integrated into the curriculum.

This PhD study aims to explore academic conceptions of their role in developing professional skills in engineering students using a phenomenographic research method. The output of the study is aimed at producing a framework, which can be used as a training tool for academic staff. The hope is that the framework will enable academics to come to a more complete awareness of how they can effect change in the engineering graduate skill level by exposing students to opportunities to develop professional skills.

The purpose of this paper is twofold. The first is to summarise the research plan, proposed methodology and progress to date. The second is to elicit critique and advice in the design of the study, including the research questions and the methods proposed.

INTRODUCTION

There is evidence that many educators have attempted to employ pedagogical strategies, such as work placement and problem-based learning to expose students to opportunities to practice professional skills. Why therefore, is there still a gap between what industry wants and what HEIs provide and whose fault is it? Industry may be demanding more than academics can deliver, in an already overcrowded curriculum with dwindling funding, particularly in an Irish context (Bourn and Neal, 2008; HEA, 2016). To close the gap, academics may need to expose students to professional skills in every module.

Accreditation requirements for engineering programmes serve as a framework for programme design. Several accrediting bodies including Engineers Ireland (EI), and the Accreditation Board for Engineering and Technology (ABET) require degree programmes to include outcomes, which incorporate what may be considered professional skills (Engineers Ireland, 2015; ABET, 2014). These skills include; self-directed working, teamwork, multidisciplinary working, ethics, communication with the engineering community and with society at large. The EI programme outcomes have been developed in consultation with employers and should therefore address concerns about professional skills from an employer's perspective. Employers in Ireland however report that they are not satisfied with the level of competence of engineering graduates in non-technical skills (IOT, 2011). This suggests therefore, that although there are processes in place which should ensure that students have opportunities to develop these skills, there is a disparity between what the accreditation paperwork requires and the skills that students actually develop. One area where this disjoint may occur is in the classroom and could be influenced by how the academic teaches or how the students learn.

LITERATURE REVIEW / RATIONALE

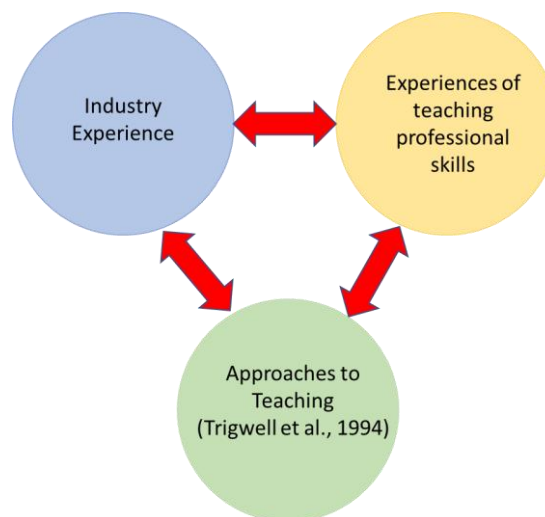
Several studies report that although there is an awareness of the importance of developing non-technical skills within students, academics do not always feel adequately prepared to teach these skills, nor feel compelled to change their teaching pedagogy (Fernandes, 2014; Miller, 2015; Fortenberry, 2011; Ambrose & Norman, 2006; Lathem *et al.*, 2011). If we assume that academics are a key driver for change in engineering education, then we need to ascertain what constitutes good teaching or more importantly good learning in relation to developing professional skills. The theory of academic conceptions of teaching provides a

lens through which to consider this aspect. When academics enter the classroom, they do so with prior conceptions of what constitutes good learning and teaching in their discipline. Prosser and Trigwell (1999) purport that the academic's conception of teaching has a direct influence on how the students learn and have created an Approaches to Teaching Inventory (ATI) survey instrument. This instrument can be used to identify how an academic approaches teaching in a particular context.

RESEARCH QUESTIONS

The research questions centre around the experience of the academic in the classroom, although we are also interested in factors which may have influenced how the academic contemplates the relative importance of professional skills. This includes how the academic approaches teaching in general (with reference to the ATI) and any influence occurring as a result of previous training in different pedagogical approaches. The authors' backgrounds have influenced their own views on professional skills and so we want to investigate if academics with an industrial background have different views to those who have a purely academic background. This research study has three aspects of study as shown in Fig. 1.

Fig. 1. Aspects of research study



The overarching research question is;

- What are the qualitatively different ways that academics experience the teaching of professional skills in engineering programmes in Ireland?

METHODOLOGICAL APPROACH

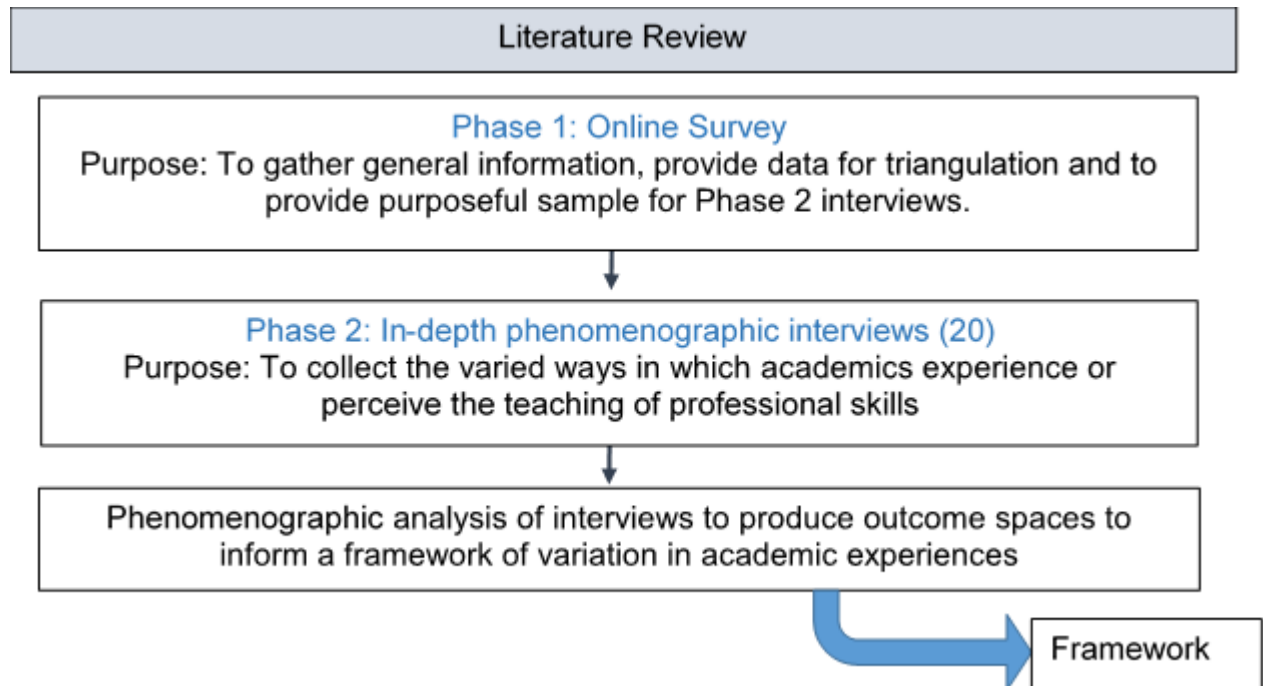
Brief description of Phenomenography

The aim of the study is to build an understanding of academics' experiences of teaching professional skills. It is not to prove a hypothesis, to look at a particular case study nor a particular group of people. A descriptive method of enquiry was needed. Three research approaches were considered appropriate for the study; phenomenology, phenomenography and grounded theory. We determined that phenomenography would best answer the research questions as phenomenographers seek qualitatively different, but logically and hierarchically interconnected descriptions that a group of people experience in relation to a particular context (Marton, 1994).

Conceptual Framework for study

This study aims to effect change in the way students are prepared for industry, particularly in relation to professional skills. This aligns well with the origins of phenomenography which was based in an educational setting. The study, while arguably based in education, focuses not on students but on the experiences and conceptions of academics. Fig. 2. outlines the conceptual framework proposed for the research study.

Fig. 2. Conceptual framework of research study showing key milestones



Data Collection – Phase 1 Online Survey

The primary purpose of the Phase 1 online survey was to enable us to undertake purposive sampling for the Phase 2 (interview phase) of the study. The survey was distributed electronically to all academics teaching on engineering programmes in all HEIs in Ireland. Only the author's own School was excluded to avoid ethical issues (Cohen *et al.*, 2011).

A list of 30 academics has been drawn up as potential candidates for interview. The selection criteria was based on unusual responses to different aspects of the online survey, in line with a phenomenographical approach which seeks variation. The progress of the study to date along with a description of how interviewees were selected will be presented at the symposium.

DISCUSSION

In this paper, we have provided a brief overview of a proposed PhD research study to elicit feedback from educational researchers in the field. We hope that the research we are about to conduct will contribute to placing increasing importance on teaching of professional skills. We hope that the outcomes will provide a framework for academic staff to reflect upon their own approach towards teaching professional skills in an engineering curriculum.

FEEDBACK FROM EERN SYMPOSIUM AND FURTHER WORK

Upon presentation of the paper at the EERN symposium, the audience gave feedback on the proposed study. One question related to the ultimate output of the study and what form that may take. The author explained that it was intended to create a training tool which may take the form of a questionnaire. This could then be used by academics to assess their understanding of the range and scope of the term professional skills and the ways in which students can be exposed to those skills within the curriculum.

The author also explained the current schedule of the study, which had just begun pilot interviews. It is intended to interview approximately 20 engineering academics in Ireland, which should provide sufficient data to allow phenomenographic analysis and outcome spaces relating to each research question.

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Paper 8: Using open ended, ill formed problems to develop and assess Engineering Mathematics competencies.

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KEY WORDS: Problem resolution, modelling, analysis, evaluation, synthesis

ABSTRACT

The purpose of this paper is to report upon how an engineering mathematics class was used to provide a vehicle for students to develop mathematical competencies and hence higher order thinking skills within the broader field of engineering education. Specifically it provided students with the opportunities to think mathematically, reason mathematically, pose and resolve mathematical problems, to use technology to model resolutions, interpret and handle mathematical symbolism and to communicate their resolutions to peers and staff.

Using the report produced by the Mathematics Working Group of SEFI (European Society for Engineering Education), which details a framework for mathematics curricula in engineering education (SEFI, 2013), a methodology was identified. This methodology was also based on work previously undertaken by the author (Peters, 2017; Peters, 2015).

In section 2.1 (p 13) the report lists and describes a set of eight mathematical competencies: (1) Thinking mathematically, (2) reasoning mathematically, (3) posing and solving mathematical problems, (4) modelling mathematically, (5) representing mathematical entities, (6) handling mathematical symbols and formalism, (7) communicating in, with, and about mathematics and, (8) making use of aids and tools. The report also points out the importance of developing assessment procedures pertinent to competency acquisition (p7).

The evidence from this investigation concludes that the majority of students found the experience challenging but worthwhile. They considered they had learnt important skills including the ability to form assumptions, persistence, time management, project management and an enhancement of their mathematical skills in relation to engineering.

INTRODUCTION

In order to start the process of acquiring these skills within engineering mathematics it was decided to expose the students to open-ended, ill-formed problems (see Appendix 1 for an example). The students involved with this investigation were first year undergraduate students studying Mechanical Engineering at Aston University.

The module was organised into three elements: semester one comprised of traditional lectures, tutorials and guided, self-directed learning on Matlab. Semester two took the form of the continuation of traditional lectures, tutorials and a problem resolution session.

For the problem (termed a challenge) resolution session, the students were put into teams and told to select a challenge from a range of challenges. Once they had selected a challenge they were expected to find and use appropriate mathematical formulae and procedures in order to develop an abstract model using Matlab. They were given talks on problem solving and about working in teams. The assessment took the form of an academic poster which would be assessed by members of the Mechanical Engineering and Design Subject Group. Prior to the assessment day, the students were given a talk on how to design an academic poster. The staff members supervising the sessions were advised not to intervene at an early stage and let the teams struggle with the challenge.

LITERATURE REVIEW

Fundamental to engineering is the necessity for the engineer to be able to analyse a problem, identify the mathematics required to translate the physical scenario into an abstract model, interpret the results of the modelling process and communicate the resolution to managers and peers (Trevelyan, 2014). The skills implicit within this process are known as higher order thinking skills and were identified in Bloom's Taxonomy (Forehand, 2005) as analysis, evaluation and synthesis. These higher order thinking skills are difficult to teach and for students to learn but are vital if the complex world of engineering is to advance. According to Sazsin (1998, p146) 'most engineering students think in terms of numbers rather than in terms of abstract concepts'. This 'attitude' towards mathematics tends to be encouraged at school or college where mathematics can be taught as a series of procedures analogous to a machine where one enters the inputs, performs a process which generates an output. At the other end of the spectrum, i.e. the professional engineer, the use of mathematical knowledge tends to be implicit. Engineers seldom apply the mathematics methods they learnt at university but frequently use the concepts when exploring engineering challenges (Trevelyan, 2014). Whitfield (1975) makes the observation that the 'personality' of the engineer when engaged in problem resolution will be important, particularly the willingness and ability to form hypotheses and to tolerate uncertainty and risk. These attributes coupled with the ability to apply learned knowledge

and skills, enables the engineer to resolve the problem creatively. To expediate the process of moving from procedural knowledge to efficient and effective problem resolution and hence being able to employ the higher order thinking skills, engineering mathematics needs to foster the ability of students to explore a challenge and apply the knowledge and skills they have acquired and have the technical lexicon to discuss their resolutions. A word of caution is necessary when attempting a problem based approach to the learning and teaching of engineering mathematics. In some cases the pre-university learning culture of students is ignored. It should be born in mind that the students will come from a highly structured environment within which they are told what to learn, how to learn and when to learn. According to Sweller (1988), some novice problem solvers tend to employ a 'means-end analysis' approach (the approach often taught to students). In other words, they recognise the end goal (the solution) and use techniques to reduce the distance from the initial state (unsolved problem) to the end state by subdividing the problem into a series of sub-goals using problem solving operators. This approach involves determining the end state, working backwards to identify sub-goals, identify operators and operations to be performed and then start from the initial state to solve the problem by working forwards towards the end state. Although this approach provides a 'safer' route to problem solving (fewer dead ends and blind alleys) it does result in high cognitive loading. Sweller (1988) suggests that the processes involved at a cognitive level are: the problem solver must simultaneously consider the current problem state, the end state, the intermediate goal states and the required procedures to reach intermediate goal states. In order to handle this amount of information a huge amount of cognitive resources have to be used (particularly memory, recall of mathematical laws and procedures) which can result in the ability to learn schemas for problem solving to be very limited due to lack of cognitive resources. This situation is further exasperated by the way in which novice problem solvers categorise problems; they tend to group according to the surface structures (Chi, Glaser and Rees, 1982). In contrast to this the expert problem solver is able to 'work forward' relying upon acquired schemas built upon the classification of previously solved problems based upon their solution mode.

The development of problem resolution schemas invariably means the student, at some point, will encounter an impasse ie. a point in the process which is unresolvable given their current knowledge and skills (D'Mello and Graesser, 2010). These critical points can result in various outcomes. The student can, by means of trial and improvement resolve the impasse, seek help from those considered to be more knowledgeable, decide the current approach is inappropriate and start again or remain 'stuck' and become frustrated and ultimately disengage from the activity. These transitions between states can be modelled by cognitive disequilibrium theory (D'Mello and Graesser, 2010). Cognitive disequilibrium is a state that occurs when students are confronted with obstacles to their problem resolution goals, incongruities, inconsistencies and anomalies.

In order to employ the Higher Order Thinking Skills (HOTS) and hence become competent problem solvers, students must be given the opportunity to develop schemas which enable

them to efficiently, in terms of cognitive resources, resolve problems. The synthesis aspect of HOTS can be directly related to schema acquisition since, by definition, synthesis is the process of combining different elements to form a connected whole (related to classification of problems). Analysis is the process of examining the problem in an organised way and evaluation is the process of determining the quality, effectiveness and efficiency of the problem resolution.

AIM AND OBJECTIVES

The question this paper seeks to address is: can the process of developing higher order thinking skills based on the acquisition of mathematical competencies be initiated within a first year engineering undergraduate programme using mathematics as a vehicle? This question can be subdivided into:

- (a) Is there a process in which explicit knowledge can become implicit?
- (b) Can students learn to form realistic and sensible hypotheses?
- (c) Can students learn to tolerate uncertainty and take risks?
- (d) Can students learn to reflect upon their resolutions to offer a sensible solution?

METHODOLOGICAL APPROACH

At the end of the programme of study the students were asked to complete a questionnaire (used in previous research) about their experience of this approach to learning engineering mathematics. The questionnaire comprised of 25 questions broken down into sections on team work, problem resolution and learning mathematics. At the end of each section, the students were given the opportunity to comment upon their experiences. The questionnaire responses (a 5 point Likert scale) were analysed using IBM SPSS ver23 utilising a frequency of response analysis. Each week the investigator would keep field notes based on the questions asked by the students and on the outcome of discussions with each of the teams. The comments and field notes were thematically analysed. Incomplete questionnaires were discarded. Ethical approval was sought and given for this investigation. 182 questionnaires were returned out of the 340 which had been issued (54% return rate). This mixed method provided the investigator with both quantitative and qualitative data which enabled him to cross reference the responses given in the questionnaire with the comments made by the students and with the observations. In this way it was possible to achieve a realistic level of certainty regarding the validity of the data collected.

KEY FINDINGS

Analysis of the questionnaire revealed that 68% of the students thought this approach improved their appreciation of the role of mathematics within engineering, 60% thought it made mathematics more interesting, and 77% thought it improved their mathematics knowledge and skills. Many students described their experience as ‘challenging’, ‘rewarding’, ‘enjoyable’, ‘hard but fun’, ‘hard at first’ and ‘interesting’. Most of the students recognised that the skills they started to develop would help them on their journey to becoming professional engineers.

The findings also highlighted that the majority of the students found it very difficult to make assumptions. They did not like the fact that they would have to find a starting point to begin the problem resolution process. Nor did they like the uncertainty around finding for themselves the mathematics they would need in order to resolve their chosen problem. They also found it difficult to cope with the notion of a problem being ill-formed with potentially multiple answers. The idea of ‘taking risks’ and not relying upon a tutor to tell them what to do, again, was very challenging for many of them.

The students’ resolutions to the example given in Appendix 1 illustrated some of the above observations. The teams that chose this particular challenge soon discovered that they could use Torricelli’s theorem to answer the initial tasks. When it came to them having to decide upon the initial conditions and the requirements they needed to take into account when designing their model, they began to struggle. For example, deciding upon an appropriate flow rate, deciding upon the amount of water they would require in addition to that required for drinking, how to collect the water and how to transport it to their dwelling.

The discussions with the students also revealed that they found it challenging when an impasse was reached in their investigation. In some cases, the impasse was resolved through group discussions, some groups would discard the resolution path they were following and restart the whole problem resolution process and others would ‘give up’ and seek help from a member of staff.

DISCUSSION

Although from a preliminary reading it may appear that this approach does not reflect much of a change from a traditional engineering mathematics curriculum. One of the reasons the module was designed in this way was to ease the transition from the highly ordered learning environment of a school or college to one where the learner was expected to take more responsibility for their own learning. It was decided that if a purely problem based approach to learning engineering mathematics was adopted then many of the students would be overwhelmed, with the net contrary result of inadvertently putting in place a

substantial barrier to learning. The different elements of the module were designed with specific purposes in mind. The traditional lectures and tutorials were elements the students would expect from a university programme and thus feel they were being 'taught'. They also provided a means of the students enhancing their mathematical knowledge and skills. The guided, self-learning of Matlab afforded the students the opportunity to begin the journey of becoming autonomous learners. In semester two the students would then have a reasonable probability of successfully resolving an open-ended, ill-formed problem. Another reason this format was adopted was to focus on what was meant to be learned without imposing a huge cognitive load. In other words, once the students were confronted with their chosen challenge, they should have had various schemas in place, albeit in a embryonic form, so they would be able to focus and direct their cognitive resources to finding a sensible, efficient and valid resolution to their challenge. The challenges themselves could be resolved with fundamental mathematics but also higher level mathematics could have been used if the teams were confident and competent in such procedures. The emphasis was very much upon the teams to decide the mathematical 'tools' they needed to resolve the challenge.

Although many of the mathematical competencies listed in the SEFI document are not explicitly recognised by the students, many of them are implicit in the process of developing a Matlab model to resolve a problem. Due to the nature in which the class was run, students had to think and reason mathematically without relying on a tutor to provide them with the 'answers' if they encountered difficulties. Many students found this extremely challenging to start with and asked questions like 'what equations do I need?', 'how do I code this in Matlab?', 'Is this assumption right?' Staff were encouraged not to intervene and encourage students to adopt the principles of problem resolution as detailed in the information they were given during the delivery of the programme. At the start the students found this response difficult to deal with since making assumptions, being allowed to make mistakes and having to find information for themselves was not something they were used to. After a few weeks the students realised that the staff would guide them but not answer specific questions.

The students were also informed to use the problem worksheets as a guide and encouraged to develop the problem by posing 'what if?' type scenario questions in order to extend the problem to reflect the realities of providing a sensible resolution. Inherent in the problem resolution process is the need for the students to represent physical entities mathematically using conventional notation. This invariably involves them in handling mathematical symbolism and having to interpret the equations and expressions in order to apply them to their particular challenge.

The assessment via a poster was introduced in order to afford the opportunity for students to discuss their work with members of staff. In the first instance, the students were expected to outline the problem, how they went about developing a resolution and how

their particular resolution provided a good solution to the challenge. They were then asked specific technical questions about their resolution. Students found this method of assessment more challenging than they first expected but some commented on how the experience built their confidence for future presentations and how it taught them to prioritise information related to their resolution.

The consensus from the students can be summarised by a statement made by one of them:

‘It was a good idea to allow students to think and build their projects around their own assumptions and thoughts. Allow them to have a better insight on how to manage team and time.’

The different forms of assessment for this module were designed to assess specific aspects. The summative, terminal examination was designed to test the students’ procedural knowledge, the Matlab model building their conceptual knowledge and the poster their communication skills and ability to work as an effective member of a team.

CONCLUSIONS & RECOMMENDATIONS

There is an inherent danger that current engineering education is producing graduates who can perform well in examinations but in reality do not possess, what the RAE has termed, the Engineering Habits of Mind (EHoM). The outcome from this educational process is that many graduates are only capable of solving well-formed, closed-problems ie. the type of question given in an examination which only requires the application of a well-defined procedure. This situation therefore requires many companies having to invest in the extensive training of graduate engineers in order for them to be useful employees of the organisation.

This study has shown that the majority of students when they first arrive at a university are competent in applying their procedural knowledge of mathematics but when it comes to analysing and resolving a simple engineering problem, they find it extremely challenging to make assumptions, identify and select appropriate mathematical constructs in order to create an abstract model and interpret the outcomes from their model. It has also shown that their ability to ask the ‘right’ questions in order to work towards a problem resolution is limited. In a purely traditional model of teaching engineering mathematics ie. lecture, tutorial and examinations, the students are rarely given the opportunity to articulate their ideas and discuss mathematics. Most traditional forms of assessment take the form of class tests and examinations which, by their very nature, make it extremely difficult to assess HOTS and do not encourage team work or the ability to communicate technical information, particularly mathematics. Unfortunately, this adherence to a ‘traditional’ approach tends to be advocated by the Professional Bodies and many universities who are more concerned with the elimination of opportunities for students to cheat and plagiarise even though

evidence (RAE, 2010) from reported conversations with professional engineers suggest that authentic problem solving, team work and the ability to communicate ideas are extremely important and more specifically: “industry ... regards the ability to apply theoretical knowledge to real industrial problems as the single most desirable attribute in new recruits. ...’ (RAE, 2007. p26).

In an ideal world engineering mathematics would be integrated within other technical subjects and hence eliminating the ‘subject silos’ of engineering programmes which are encouraged by a modular based system. A more project based approach should also go some way to encourage students to become ‘deep’ learners rather than ‘strategic’ ones where they focus on passing modules in the hope of accumulating enough credits to pass the year. The totally project based approach has numerous challenges, such as accreditation, assessment, moving away from a teacher-centric approach to a student-centred approach and the management of student and staff expectations.

Engineering schools who are actively looking for alternative ways to facilitate the learning of engineering mathematics must be cognisant of the entry profiles of their students. Universities who are considered to be high tariff institutions would probably attract students who are confident and competent enough to cope with a project based approach whereas institutions at the other end of the scale, or who lower entry criteria for clearing, would have to ensure a robust academic support structure was in place to provide a safety net for students who would struggle in such an environment.

By the end of this module, many students appreciated the opportunity to start to develop the skills required by an engineer in the 21st century. In terms of this investigation, the students started to develop the stated mathematical competencies and hence develop schemata whereby explicit knowledge became implicit. They also developed in confidence and learned to trust their own abilities with the realisation that they may not always be correct. They also began to develop a critical evaluation mind-set whereby they were able, as a team, to look at their resolutions and decide whether they were sensible.

In order to continue the development of EHoM (Lucas, Hanson, & Glaxton, 2014) this approach of allowing students to tackle ill-formed, open-ended problems should be continued throughout their time at university and incorporated into the other subjects they study. This process will not produce engineers who are competent on graduation to resolve the many complex problems inherent in our modern world but it will give them a firm foundation and mind set on which companies can shape the engineers they require.

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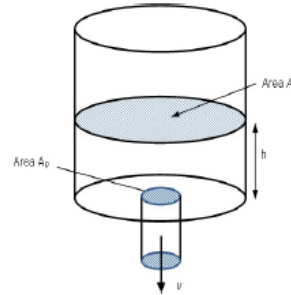
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Appendix 1.

Applying Mathematics - Supplying Water

Challenge level - 2 Maximum marks 80



Initial Tasks

- Find a differential equation relating the height, h of the water at a time t .
- Solve this equation for the initial conditions $t = 0, h = 2$.
- How long, in minutes, does it take to empty the tank which is $2m$ full?
- Decide how much fresh water you require per year and design an appropriate size tank.

Main Task

Using Matlab develop a mathematical model to investigate different sizes of tanks and different flow rates so you have access to water all year round.

Scenario

You have decided that you have had enough of living the 'rat race' culture prevalent in the UK. You have done some investigative work and decided to move to Northern Belize, buy some land and build a new life where you are in control. One of the first tasks, after building a shelter, is to build a water storage tank so you can have fresh water all year round. In your investigations you found out that Northern Belize has a rainy season between June and November where, on average, 1524mm of rain falls.

You decide upon a cubical tank with a water outlet at the bottom. Your initial 'guess' at the dimensions for your tank were: sides $3m$ with a drain hole of diameter $0.1m$.

Unfortunately you can only find information on a cylindrical tank as shown in the diagram.

Paper 9: Peer Tutoring in Maths: What students think is important

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KEY WORDS: Maths: Tutors: Peer: Students. Foundation Year

ABSTRACT

Based within a UK School of Engineering this paper addresses a problem that is endemic across much of the UK Engineering Higher Education Sector, that of how to better support first undergraduate students who arrive at university lacking sufficient competency in Maths. Within the University concerned, students who do not possess suitable GCE 'A' levels are offered an alternative route into higher level study in the form of an Engineering & Applied Science Foundation Year Programme (FYP). Between the academic year 2014-2015 and 2015-2016 numbers of students enrolled on the FYP grew from just under 90 to well over 300. Whilst many subjects can successfully be taught at FY level in a large group setting, Maths, on the whole, cannot.

Faced with a shortage of Maths Tutors able to support 300+ Foundation Year Engineering Students, the decision was made to put into place a 'Peer Tutoring' system whereby second year Engineering & Applied Science students would be paid to act as 'Maths Peer Tutors' for 6 hours per week. A total of 28 Maths Peer Tutors were selected out of 60 applicants. By focusing on the Maths Peer Tutors perspectives, as opposed to that of the Tutees, this paper takes a unique look at the student experience; concluding that in many respects universities do not make best use of their greatest asset – their own students!

INTRODUCTION

Borne out of a need to provide high quality intensive support to a large group of Foundation Year Engineering students, the Maths Peer Tutoring Project was initially viewed with some suspicion and resistance by the senior Maths Lecturer who had previously employed Post-Docs and PhD Students to support teaching. Despite such reluctance, Maths Peer Tutoring proved to be a great success, with small groups of students being tutored by their slightly more senior peers. Indeed, the approach discussed in this paper has gone from strength to strength, evolving into an embedded system of student support which continues today.

In seeking to look beyond the immediate success of the project the decision was made to take a different stance and to critical examine the perspectives of the Student Maths Tutors'

themselves. Hence the research question *“What characteristics do Student Tutors believe they themselves bring to Maths Tutoring?”* was formed. Beginning by examining the demographic and educational characteristics of the 28 Peer Tutors, this paper provides an overview of the findings of a short qualitative study in which the Tutors were asked three questions: What experience of tutoring do you have? Why do you feel you should be employed as a Maths Tutor? What personal attributes can you bring to the role of Maths Tutor?

Using grounded theory techniques the data was analysed and two main themes are identified: Intrinsic & Extrinsic Factors. The data is presented and brief discussion section considers the wider implications of the study findings for Maths Education at foundation and first year level.

BACKGROUND / CONTEXT

As at a time of almost unprecedented political and scientific change and uncertainty, society is increasingly turning to engineers to solve a series of global challenges (see NAE, 2018, for further discussion). Yet, despite the high profile given to such global problems, in the UK young people continue to view Engineering & Applied Science negatively. Moreover, the numbers of students achieving sufficiently high GCE ‘A’ level grades in Maths, Physics, Chemistry and Technology to be able to study Engineering at University has decreased markedly over the past two decades (DBIS, 2014; Osborne et al, 2003)

The inevitable result of this is depicted below in Figure 1, which shows that the majority of current university students are enrolled upon Business, Arts and Humanities Programmes, with almost twice as many studying Business & Administration than Engineering and Technology (HESA, 2018).

STUDENT SHORTAGES IN ENGINEERING: WHAT IS THE SOLUTION?

Over recent years one of the solutions to shortages in numbers of young people selecting to study engineering and applied science at university has been the introduction of ‘Foundation Year (FY) Programmes’. Although there does not appear to be a single definition of exactly what constitutes a FY Programme, it is safe to suggest that the majority are aimed at students who do not possess the prerequisite grades in the subjects required to study a particular subject or programme in Higher Education. FY Programmes may be taught at University or in Further Education, but, unlike ‘Access to H.E.’ courses, FY Programmes afford students all of the benefits of full time university study, including access to funding.

Providing pre-university level education to students who may not have achieved well at GCE ‘A’ level is, for many universities, a step into the unknown. Indeed, it would seem that there is a high risk that such programmes may well attract even higher numbers of students unprepared for the independent nature of higher level study than those entering university through traditional routes (Smith, 2010, Paton, 2012). Moreover, the likelihood that FY students will possess low levels of Engineering Capital (Clark & Andrews, 2017) makes the

task of running a University Year 'Zero' (UY0) programme educationally challenging. Yet, without a doubt, FY Programmes have a unique and increasingly important role to play within the 'university portfolio'. Such programmes are not only a tool for tackling low levels of educational and social capital (Bourdieu, 2011), they provide a purposefully constructed 'stepping stone' between school or college and university.

Figure 1: Student Numbers & Subject Areas 2016-2017 (HESA, 2018)

Subject Area	Female	Male	Other	Total
(1) Medicine & dentistry	37,430	27,645	35	65,110
(2) Subjects allied to medicine	229,905	60,770	95	290,770
(3) Biological sciences	142,585	83,730	85	226,395
(4) Veterinary science	5,520	1,625	0	7,145
(5) Agriculture & related subjects	11,815	6,835	5	18,655
(6) Physical sciences	39,200	55,925	45	95,170
(7) Mathematical sciences	16,265	27,580	35	43,880
(8) Computer science	17,390	83,710	45	101,145
(9) Engineering & technology	29,025	136,085	45	165,155
(A) Architecture, building & planning	19,350	31,905	10	51,265
Total - Science subject areas	548,485	515,810	405	1,064,700
(B) Social studies	139,915	81,685	115	221,710
(C) Law	55,985	33,715	35	89,730
(D) Business & administrative studies	164,955	168,415	50	333,425
(E) Mass communications & documentation	29,820	20,560	40	50,420
(F) Languages	75,615	31,365	60	107,040
(G) Historical & philosophical studies	46,260	39,110	85	85,455
(H) Creative arts & design	113,275	62,235	190	175,700
(I) Education	115,560	35,455	40	151,060
(J) Combined	24,165	14,470	5	38,640
Total - Non-science subject areas	765,550	487,010	620	1,253,175
Total - All subject areas	1,314,035	1,002,820	1,025	2,317,880

Initially established with the specific purpose of attracting those students who had failed to achieve the pre-requisite grades in Maths & Physics to study Engineering, the UY0 FY Programme now attracts between 250 and 300 students per year. For the first few years of

the Programme student numbers were much lower and so Maths taught in a much more traditional manner (in a large group setting led by a single lecturer supported by postgraduate students and / or post-doctoral researchers). One of the key issues with this approach was that students, already lacking in confidence when it came to Maths, struggled to keep up. This resulted in a high failure rate in the Maths module, meaning that many students simply didn't achieve sufficient credits to continue onto a Bachelor's Programme in Engineering in the University concerned (although many went on to study other subjects following the FY and others transferred to other universities). In an attempt to address this issue, the decision was made to move from a 'large group' teaching approach to small tutorials. This entailed dividing the students into small groups of between 8 and 10, and providing each group with six hours per week intensive contact time with a dedicated Maths Tutor.

STUDY APPROACH

- Objectives and Research Question

With the primary objective of building Maths and Engineering Capital within the School, the decision was taken to offer second year undergraduates the opportunity to apply to work as Maths Tutors, on a paid basis, for 6 hours per week. Over 100 students initially applied, 60 were interviewed and 28 appointed and trained.

Starting with the research question *“What characteristics do Student Maths Peer Tutors believe they themselves bring to Maths Tutoring?”* the study draws upon data collected from the student Maths Peer Tutors.

- Methodology

Twenty-eight qualitative questionnaires were distributed during a formal training session. Data from these questionnaires has been analysed in two distinctive stages, the first comprising a quantitative analysis of the sample demographic data; and the second involving a grounded theory analysis of Peer Maths Tutors replies to three open-ended questions:

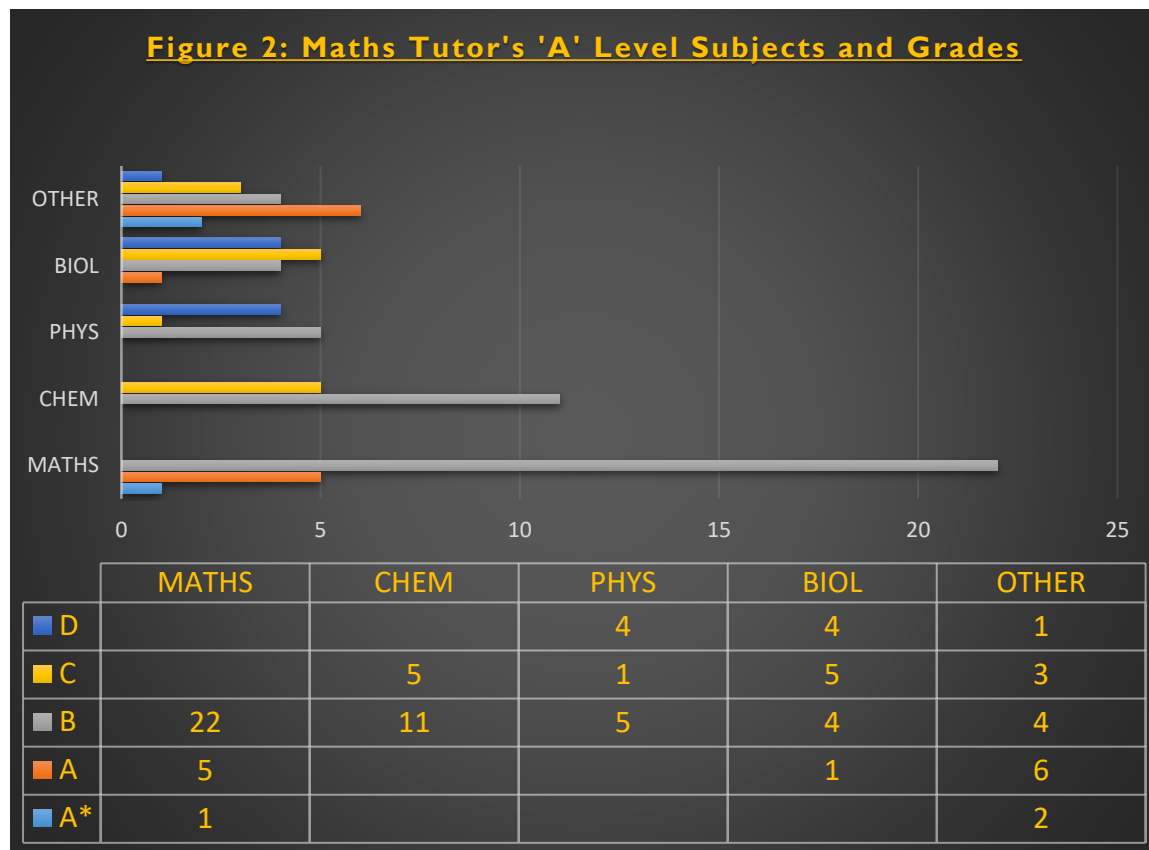
1. What experience of tutoring do you have?
2. Why do you feel you should be employed as a Maths Tutor?
3. What personal attributes can you bring to the role of Maths Tutor?

FINDINGS: QUANTITATIVE DATA

An analysis of the sample demographic and educational characteristics revealed that equal numbers of Males and Females were employed as Maths Tutors (14 of each gender). This was not a purposive management decision but instead reflected the quality of candidates interviewed who were judged on their ability and transferable competencies. Conversely,

the ethnicity of the sample did reflect the wider School with 8 of the sample from a 'White' ethnic background and the rest from BAME groups.

Figure 2 below provides an overview of the Maths Peer Tutors GCE 'A' level results and shows that every individual within the sample had achieved at least a Grade 'B' in Maths, whilst 16 of the students had an 'A' level in Chemistry, 10 in Physics and 14 in Biology.



Other quantitative data about the sample revealed marked differences between the genders in terms of grades and subjects studied.

FINDINGS: QUALITATIVE DATA

In analysing the data, two main themes emerged with regards to the personal characteristics that Student Maths Peer Tutors believed they possessed: Intrinsic Factors (Individual Abilities and Characteristics): and, Extrinsic Factors (Motivations and Drivers).

Of the two themes, Intrinsic Factors proved to be the largest determinant with all of the 28 students self-identifying as being strong in this area.

Intrinsic Factors

○ Self Confidence & Empathy

Perhaps not surprising given the fact that all of the sample had been employed as Maths Tutors and were successful in undertaking the role, the vast majority expressed high levels of self-confidence and belief in their own abilities:

I am a very motivated and motivating person, and am also patient. I tend to be enthusiastic about maths and pass this on to other students [Chem Eng Student. M]

As a mentor I offer myself as a confident individual who has exceptional communication skills. I have experience as a tutor and I am able to do the role. [Chem Eng Student. M]

I am easily approachable and offer enough help in different ways to show my commitment to someone when being a mentor [Maths Student. F]

I am confident that I transfer my knowledge to the mentee in a way they clearly understand. For example, by finding out their individual learning methods. I help boost their academic confidence by promoting a sustainable method of learning [Chem Eng Student. F]

Such confidence had a positive effect on the Tutees, many of whom arrived at university lacking in self-efficacy having not achieved the 'A' level grades they had expected.

Somewhat surprisingly, the theme of learning styles was mentioned by a three of the Peer Tutors who were themselves Chemical Engineering Students:

I know there are many different ways that we can learn – through mind maps and flash cards etc. I would try to show these to the students and suggest different ways they could become more independent. I would also bring confidence and enthusiasm which I think is very important [Chem Eng. M]

By acknowledging that there are three different types of learner, visual, kinaesthetic and auditory (and even a mix of these) I am able to help students find out how they learn. This can greatly benefit their studies and help them revise more effectively [Chem Eng F]

Although self-confidence was undoubtedly the intrinsic factor most commonly described by the sample, other characteristics such as empathy and role modelling were also raised, although somewhat surprisingly, those Peer Tutors who were themselves studying Maths at 2nd year level who were most prolific in suggesting that empathy was key to Maths Tutoring:

It took me about 4 years of preparation to get to the level in maths I needed to study at university. This means I can understand the position of foundation students and will be able to provide them with the right amount of help they need to succeed. Students can feel comfortable when seeking my support as I am also a student. I will do my best to provide help in the most friendly and professional manner. [Maths Student. M.]

After having a peer mentor in the first year I decided to become a peer mentor this year. This was so that I could help undergraduates settle into university life and ease them of any nervous energy and worry. Being on both sides of the scheme allowed me to understand what makes a good mentor and learn skills to become a better mentor. [Maths Student. F]

○ **Hardworking & Caring**

Whilst confidence and empathy were two of the most widely expressed characteristics in terms of Peer Tutors' perspectives of what makes a 'good maths tutor' the idea that they were 'hardworking' was also widely mentioned:

I'm a very hardworking and enthusiastic individual who loves to give back to others. I'm very patient and have good communication skills. [Business & Maths. F]

I am a hardworking undergraduate with strong problem-solving skills and an excellent understanding of mathematical concepts. I am capable of presenting my knowledge to others. [Maths. M]

I believe I am a good mentor as I am a hardworking, determined and dedicated person. I will make sure every student is satisfied with the session and will try my utmost to meet the needs of the students I am mentoring [Maths. F.]

Whilst around half of the Tutors described themselves as 'hardworking', a larger majority described how being of a 'caring nature' was important:

As a mentor I can be extremely motivating to students. I can be caring and patient whilst helping students with various maths problems. I am always able to throw myself into new projects and am consistently enthusiastic. [Chem Eng. M]

I would bring enthusiasm and dedication to the role. I am someone who works through problems methodically and feel this is the best way to mentor others. [Chem Eng M]

I care about other students and give maximum dedication to passing on my exceptional mathematics knowledge to them [Chem M]

Whilst intrinsic factors were expressed by all of the sample, extrinsic factors such as being 'good' or 'very good' at Maths were also identified by the majority of the sample.

Extrinsic Factors

○ Maths Capabilities & Experience

Of the 28 Tutors, only a small minority did not discuss their own capability or positive experience of Maths. For the majority, a love of Maths and an ability to explain mathematical concepts and ideas in a clear and accessible manner proved to be a driving factor:

I can offer numerous ways of helping first year students by explaining the complex aspects of maths. I obtained a first in the maths modules overall [Chemistry. M.]

I have completed the first year of my degree and achieved 80%. I believe I have additional knowledge and experience which will benefit other students [Chem Eng F]

When the students find the lecturers methodological approach to problem solving too complicated I can offer my tips or an alternative method of understanding the problems. this may allow them to gain confidence towards tackling the questions without having to ask for help in future [Chem Eng M]

I have the appropriate A level grades and have passed first year maths. I believe I have the skills and foundational knowledge required to teach foundation level students [Maths. F]

I am able to explain and clarify 'A' level mathematical concepts to students in an efficient yet friendly manner, without making them feel upset or patronised. I believe the whole idea of peer mentoring is that students feel more relaxed around their tutors and so are more likely to ask questions, even if they think those questions might be 'stupid questions'. This helps them learn and understand concepts in more depth [Maths F]

I can offer a detailed understanding of maths as I achieved a 1st in the 1st year. I am able to communicate maths to my peers very effectively and in doing so help deepen their understanding of maths [Maths M]

I want to act as a maths mentor because I feel I am in a great position to pass my knowledge on to others and help them better themselves. Having gained good maths grades at GCSE and A level I have experience of approaching problems in different ways. I would like the opportunity to pass this experience on. I think mentoring would be a valuable experience for me, this means I would gain as well as those being mentored [Chemistry M]

Whilst almost all of the students pointed to their capabilities and experiences in Maths, a minority looked beyond this to discuss work experience, both as a factor with regards to previous experience and as a driver to promote their own employability.

- Previous Work Experience

Within the University where this exploratory study took place, the majority of students work part-time whilst at University. Moreover, there is a strong emphasis on ‘work-experience’ and around 60% of the students undertake a paid professional work-placement in the third year of their studies. A small number of students described how prior work experience had provided them with transferable skills and competencies that they were able to put to good use in their role as Maths Tutors:

Having worked in retail for the last three years as well as my experience of mentoring in the sixth form I have gained excellent communication skills. I can work well with a wide-range of people and adapt effectively to new situations presented. I am also a very approachable person and as a mentor would aim to make those I’m mentoring feel as comfortable as possible. I am very good with time management. I am also very patient [Chem Eng M]

From previous work experience I am very confident and have excellent communication skills. I am comfortable listening to someone then helping them identify a solution to a problem. [Chem Eng F]

Conversely, only a handful of students indicated that they were motivated by a need to improve their CV:

Doing this will help make my CV stand out from the crowd and give me many skills such as team work, organisational and communication skills [Chem Eng M]

As teaching Maths is my career aspiration I am willing to devote extra time to ensure students understand and are able to apply maths knowledge to different scenarios [Maths & Bus. F.]

I would like to acquire some work experience in a maths profession and I think that working as a maths mentor would be a valuable experience; something to add to my CV which will give me an advantage when applying for a placement [Maths M]

DISCUSSION AND CONCLUSION

This short exploratory study provides the unique opportunity to consider what characteristics Student Maths Peer Tutors believe are necessary to successfully tutor other students. In looking at both the Intrinsic and Extrinsic Factors described by the students, one of the most surprising findings relates to the Student Peer Tutors levels of confidence in the subject itself. Indeed, the majority of the Student Peer Tutors had not achieved exceptionally highly at school, and yet felt that they offered ‘excellent’ maths abilities and knowledge. In considering this further and looking at the wider context, it may be postulated that such confidence has its origins in the way in which Maths is taught in the first year at the University concerned. By adopting teaching pedagogies that purposefully

enhance students' attitudes towards the subject, it seems that the first year Maths Lecturers are succeeding where schools fail.

That equal numbers of female and male students were appointed as Maths Tutors is important to note as around a quarter of the undergraduate population within the School of Engineering are female (and hence are very much in the minority). Despite this, when analysing the qualitative data it would seem that there is no difference between male and female student tutors' self-confidence or perceptions of their ability in Maths or to be a Student Maths Tutor.

In conclusion, the study has many limitations, not least with regards to the sample size or the limited nature of the questions. Furthermore, circumstances have meant that it has not been possible to collect further data although the Maths Tutoring Programme described in this paper continues to run successfully.

This paper makes an important contribution to current debates about University Maths Education in that it focuses entirely on Undergraduate Student Maths Peer Tutors perspectives. In doing so the paper adds to current debates around Maths Education in University and raises the important question of *whether the majority of universities are failing to make best use of their greatest and most appropriately placed resource: that of undergraduate students?*

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Paper 10: Trust and Conflict in group learning: The role of computer orchestrated learning

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KEY WORDS: Group work, teamwork, Flipped Classroom, Computer Orchestrated learning, engineering education.

ABSTRACT

Engineering Education practice makes use of several group work scenarios such as Flipped classroom (FC) and Project based learning (PjBL). However, there are very few studies within Engineering Education Research body that investigate the interrelations between psychological constructs, such as trust and conflict management styles within such team-based settings. This paper presents preliminary results from one arm of a research project that investigates the inter-relationship between trust and conflict between teams of engineering students within a Flipped Classroom setting. The second arm (not reported here) investigates the same within PjBL settings. Students learning together in small teams used Computer Orchestrated Group Learning Environment (COGLE) as a teacherless intervention when mastering electronic engineering topics needed for successful performance within a FC session later on. Students took a knowledge based pre-test and filled in a self-reporting survey about their trust levels in their teammates at various stages of this study. They also completed the multi-item *Style Matters* instrument in order to capture their preference for approaches to conflict management when working with others in teams. In as little as 4 weeks of using COGLE, the students report increase in trust levels in their teammates. Within the same period all students expressed that their most preferred conflict management style was that to use a *collaborative* approach to team working. Apart from these gains, the students also reported a high learning gain of 32.61 (SD=14.75). Interview data from these participants is being analysed and is not included in this paper.

LITERATURE REVIEW AND RATIONALE

Constructivism based approaches, like Problem and Project Based Learning (PjBL) are valuable for engineering education (EE) as they closely model how collaborative problem solving in industry works (Graham 2010; Hanney & Savin-Baden, 2013; Harmer & Stokes, 2014). However, managing and achieving high-quality collaborative work in PjBL is seen as challenging and resource hungry (Kokotsaki et al, 2016; Graham, 2010 and Harmer & Stokes, 2014). Harmer & Stokes (2014) highlight the challenges in dysfunctional groups as: the presence of 'free riders' or 'social loafing'; situations of conflict; lack of training; and not valuing group work enough. Supporting and monitoring these can be resource intensive and many UK Engineering schools have either not adopted PjBL or are dependent on staff good will (Graham, 2010). Given the demands of PjBL, students may face added difficulties when dealing with with socio-emotional, communicative and cognitive challenges inherent in collaborative situations (Graham 2010; Hanney & Savin-Baden, 2013; Harmer & Stokes, 2014; & Sajadi & Khan, 2011; Anderson et al., 2018). Staff supporting PjBL students may feel it is reasonable and economic to award a 'group mark' to be split by the students themselves. However, due to the stated inherent challenges, this does not always equate to a fair system. Looking at existing solutions, MIT's GEL programme or Aalborg University's PjBL programme, provides additional training for students on Leadership skills (Harmer, 2014), Cooperative learning, Project Management (Lehmann et al, 2008) and training in group work. Such additional and non contextual support, add to the demands on HEIs. Besides the evidence for the benefits of such training in academic contexts is limited.

Like PjBL, Flipped classroom (FC) approach is also used within EE settings as an active learning approach (Karabulut-Ilgu et al., 2018). FC employs,

"group-based interactive learning activities inside the classroom, citing student-centered learning theories based on the works of Piaget 1967 and Vygotsky."

(Bishop & Verleger, 2013)

Students are required to engage with content prior to working collaboratively in class to enhance their knowledge and understanding. However, FC also suffers from the same challenges related to collaborative learning already highlighted above (Karabulut-Ilgu et al., 2018). Students often: do not attend sessions; miss engaging with specified content; are overwhelmed by the active engagement required; and do not all or fully engage in the activities in class making FC less effective than what it can be (ibid).

This highlights a need for a rethink on PjBL support and FC implementation. Zimmerman's social cognitive model of self-regulation (1989) and its extension into the social by scholars through socio-cultural influences (Hadwin, Järvelä, and Miller, 2011; Järvenoja et al., 2017)

presents the opportunity for such a rethink. Several CSCL and Psychology researchers have focussed on conflict, social loafing, communication and self and co-regulation over the past two decades (Dillenbourg & Hong, 2008; Fischer et al., 2013; Vogel et al., 2017; Malmberg, Järvelä, and Järvenoja, 2017). CSCL developers use Script Guidance Theory (SGT) for scripting conflicts to enable learning and scaffold collaboration (Fisher et al., 2013). Though there is limited success with scripting socially shared levels, scripting self and co-regulation has helped learners improve their team effectiveness by improving their group-awareness, socio-metacognitive, socio-emotional regulation (Dillenbourg, 1999; Winnie and Nesbit, 2009; Tchounikine, 2016; Näykki et al., 2017; Bakhtiar et al., 2018; Borge et al., 2018).

Within EE, Borrego et al. (2013), highlights multiple models involving constructs such as social loafing, trust, conflict and team interdependence for improving team effectiveness. They call for EE researchers to focus on multiple psychological constructs, in real teams, thereby 'embracing the complexity' that is often left out in single construct, experimental psychology studies.

AIM AND OBJECTIVES / RESEARCH QUESTION(S)

This arm of the PhD study is a repeat case study of an approach that involves modifying Flipped Classroom approach by collaborating at the time of knowledge acquisition and investigates how the trust between team members build with the use of COGLE and how it affects their conflict management styles over time. In this arm of the study the students first used COGLE to learn and master the content together without any teacher intervention instead of engaging with the content individually. Later, they used their knowledge on the topic and about each other to design together a circuit as their collaborative FC activity. This study sets out to capture the answers to the following questions:

RQ1: How does computer orchestrated group-wide mastery of engineering topics, achieved using COGLE in small groups of learners, affect their individual skills and attitudes relevant to collaboration within a Flipped Classroom activity?

And in particular,

RQ1.1 How does the use of COGLE affect a learner's attitude to conflict management?

RQ1.2 How does the use of COGLE affect a learner's development of trust in group members?

METHODOLOGICAL APPROACH

Three groups of three students each from a Level 3, foundation degree programme, took part in the study. Students joined teams randomly as they joined the study. This approach was taken to study teams where students did not know each other from before and it achieved that. The study involved taking a pre-test on the subject topics at the start and completing a base line survey on team trust and the *Style Matters* survey to capture their preferred conflict management styles (Kraybill, 2011).

Students then took part in four two-hour sessions where they watched videos on Fundamentals of electronic engineering suitable to their level within COGLE together with the teammates. COGLE would award mastery of the content to the whole team only when all the students answered 10 questions correctly in a row. After each question, where at least one of the student in the team was incorrect, COGLE orchestrated interactions between each team member in order to help mastery of content by every member in the team (group-wide mastery). When all students were incorrect, COGLE moved on to the next question and made note of the topic area to provide support through a video later on in the session.

After completing the four learning together sessions, the students completed a post-test on the topic studied and the team trust and *Style Matters* surveys. A Flipped classroom collaborative activity followed the four sessions and students completed it with their teammates.

Whilst the primary aim was to capture changes in team trust and conflict management styles, the subject pre and post-test was also used evidence the learning that took place within COGLE sessions. The survey captured quantitative changes in the different facets of trust between students, one of which was cognitive trust. The pre and post subject tests would help understand the changes in cognitive trust between the teammates. Table 1 lists all the different facets of trust under investigation in this study and the respective survey items. Students were interviewed after the study to add qualitative richness to the changes captured quantitatively.

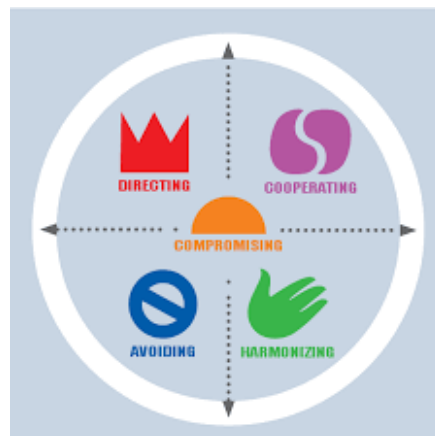
Additionally, the *Style Matters* survey helped map students into different quadrants shown in Figure 1 below and any changes before and after the COGLE sessions. The cooperating style to conflict management is the ideal style that benefits from a high dual focus on 'task at hand' as well as 'interpersonal relations' needed in building a team from a group of people. Avoiding conflicts being an approach that is least beneficial within teamwork as in

doing so, people focus on neither relationships (and ignore or not take part in discussions) nor on the ‘task at hand’. The *Style Matters* inventory help map a respondent’s preferred order of these conflict management styles.

Table 1: Facets of Trust under investigation and the respective survey items.

Team trust survey (Scale 1=SD; 7=SA;) Adapted using theoretical foundations provided by Mayer et al. (1995).	
<i>affective_trust (benevolence)</i>	1. my teammates help me when I need it.
<i>cognitive_trust (ability)</i>	2. my teammates are knowledgeable in the topic area we are studying together.
<i>conative_trust (integrity)</i>	3. my teammates can be counted on.
<i>affective_trust_reverse</i>	4. My teammates are unhelpful. (r)
<i>Cognitive_trust_reverse</i>	5. my teammates have very little knowledge in the topic area we are studying together. (r)

Figure 1: Different conflict management styles captured by the *Style Matters* Inventory (Kraybill, 2011).

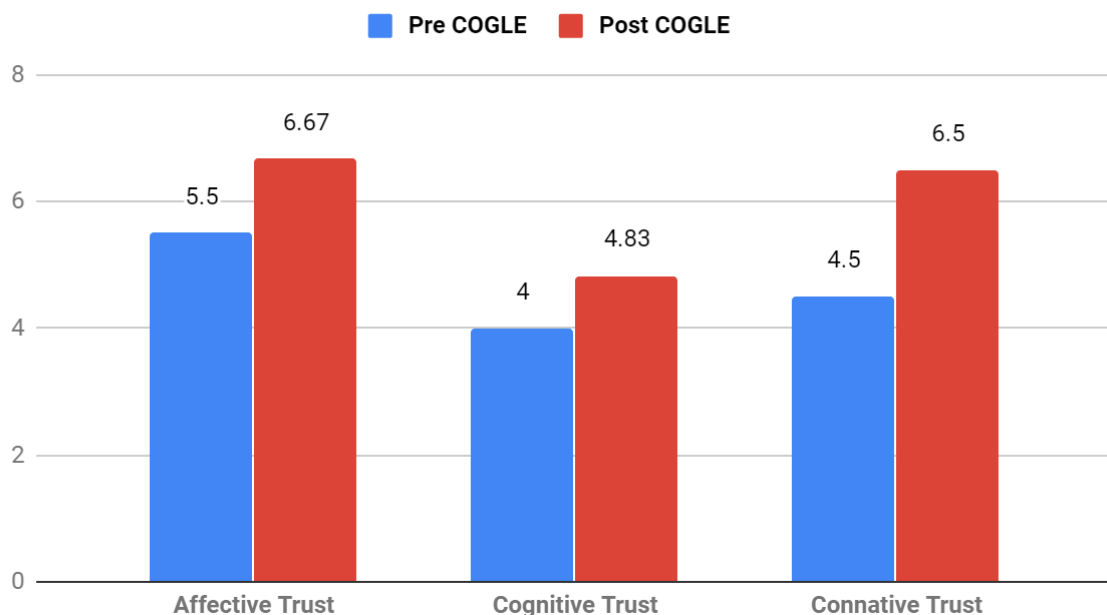


KEY FINDINGS & DISCUSSION

Analysis of the team trust and *Styles Matter* inventories revealed positive results in terms of how these constructs over only four COGLE sessions. Students reported an increase in their trust levels in their teammates as shown in Figure 2. For all three types of trust shown in Figure 2, there is an increase in the average trust levels. This shows that over a short period of four two-hour sessions of learning together using COGLE makes it possible for teammates to trust each other overall. This proved beneficial when working in their teams designing the circuit collaboratively during the Flipped Classroom session. Having high trust is known to speed up conflict resolution.

Figure 2: Average self-reported trust scores pre and post four COGLE sessions.

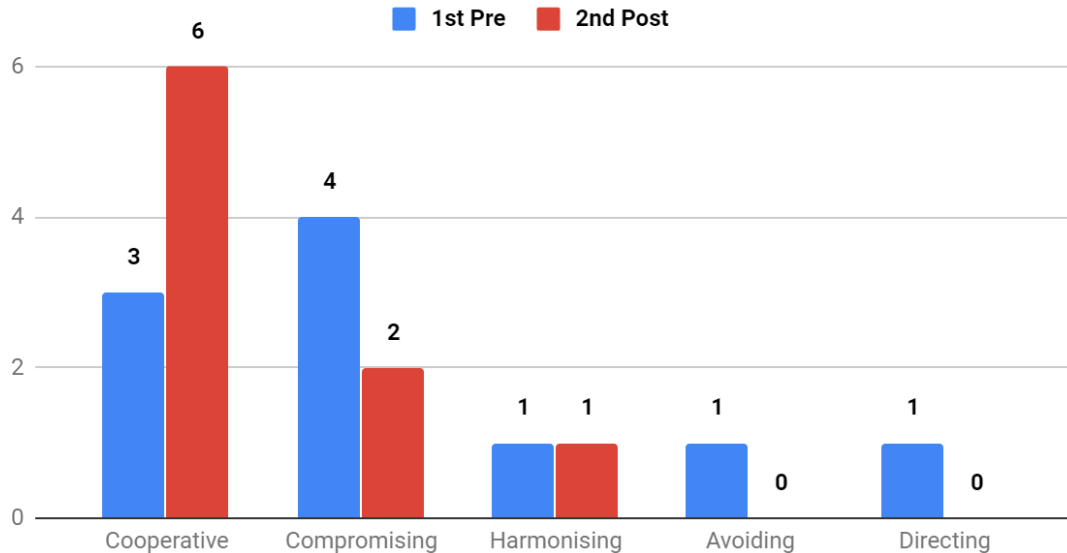
Pre and post COGLE average individual trust scores



After using COGLE, all students reported their most preferred conflict management style as 'Cooperating', which is the most beneficial style for team working (see Figure 3). The way COGLE works encouraged them to consider resolving their differences and working collaboratively when they were learning the content before their FC activity. This exposure was beneficial for the collaborative activity of designing a circuit together. Moreover, none of the other conflict management styles did not see any increase after the use of COGLE.

Figure 3: 1st preference Conflict Management style counts pre and post COGLE use.

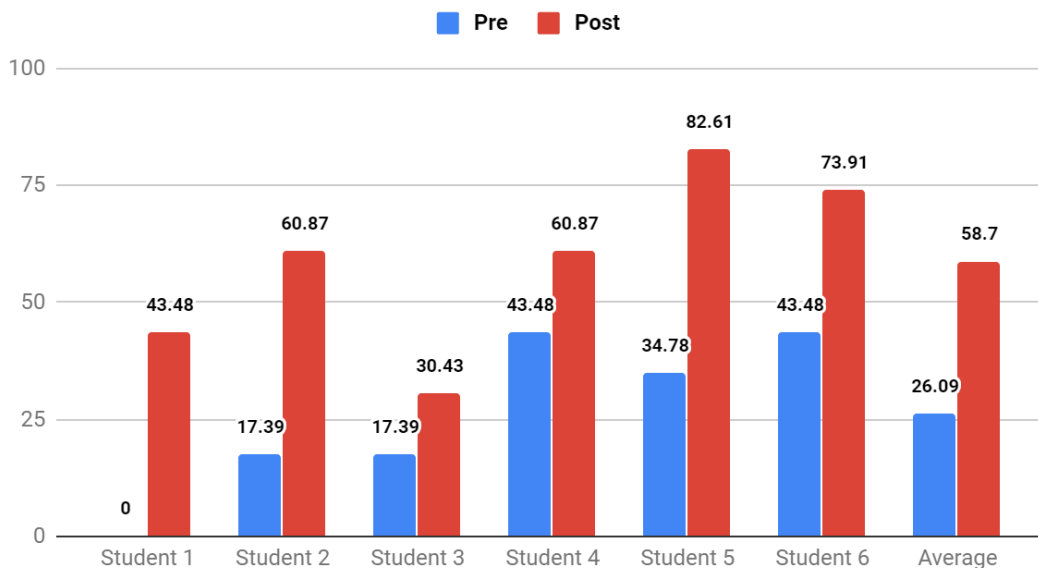
Conflict Management styles - 1st preference counts before and after COGLE use.



Learning through COGLE resulted in an average learning gain of 32.16 (SD=14.75) was noted for these students (see Figure 4). Peer interactions and a group-wide mastery based approach helped prepare learners for the collaborative activity during the FC session.

Figure 4: Average and individual test scores pre and post COGLE sessions for each student.

Pre and Post test scores



The interview data has not yet been analysed and it is expected that it will provide rich insights that will help study interrelations between trust and conflict and the conflict management styles of the students. Below are some sample comments reported in free text survey questions:

"It forced students to think about the reasoning behind their answers so they could easily discuss how they arrived at their answer with the rest of the group."

"Even when they thought they were right and it showed they were wrong, it allowed me to explain to them why they were wrong and increase their understanding of the topic."

"The system improved the situation by forcing someone to step up and discuss their answer, making us listen and understand but also making the person speaking understand more what they are talking about. One situation was not helped as the person being asked to talk did not know the answer. Perhaps a "re-election system" could be used if the first person does not know the answer."

The quantitative data analysed so far is encouraging as it shows a positive movement in trust scores as well as a collaboration supporting most preferred conflict management style. The data collected show how using COGLE can change these constructs (self-reported values). However, when dealing with psychological constructs, in light of the debates around such research, qualitative data analysis alongside the quantitative data should help add valuable insights that explain why these construct move favourably for team working. This and to understand the interrelationship between conflicts and its impact on trust development and vice-versa, the interview data is being coded ground up in order to find themes that link these two and help explain the reasons behind favourable movements in the data.

CONCLUSIONS, LIMITATIONS & RECOMMENDATIONS

This paper reports preliminary results from a PhD project that sets out to evaluate COGLE and study the interrelationship between trust and conflict and conflict management styles. Developing trust between student team members helps to resolve conflict and is well known in the research literature. However, under what circumstances do conflicts themselves lead to a build-up in trust is understudied. Initial findings suggest that COGLE encouraged conflict resolution relating to content knowledge by orchestrating discussion between teammates, pairing students with opposing views. In parallel, the trust between the team members in this study also grew.

The results from this study will be compared with that from two other case studies. First case is where COGLE is used within a PjBL setting that involves learning together using COGLE for 7 weeks followed by a collaborative PjBL design activity. It will also be compared with another activity where COGLE is not used within a PjBL setting. The within and between group comparisons in the survey and interview data is likely to result in stronger evidence needed for analytical generalisation as is often the case with case studies with smaller sample sizes. In order to generate enough evidence to claim any generalisability over different student populations, a larger study will be carried out later.

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Theme Summary: Teaching Innovations

Five papers from a diverse range of authors and Higher Education settings are included within this section. Starting with an analysis of Attendance Monitoring from Tewkesbury et al, University of Portsmouth, evidence is presented that contrary to commonly held beliefs, Attendance Monitoring has little or no impact on attrition and failure (focusing specifically on an Engineering Foundation Year Programme).

Following this, a paper by Munoz-Escalona et al represents a collaboration across three countries, Scotland, Spain and Venezuela and five universities. Highlighting the benefits of on-line, international learning, the paper also discusses the benefits of cross-cultural working in promoting students' communication skills.

Continuing with the theme of on-line learning, the third paper by Hidalgo et al, Open University, shows how Learner Analytics may be used to improve student engagement. An analysis of the use of on-line laboratories in distance learning is given.

A somewhat controversial paper submitted by Ballatore et al, Politenico Di Torino, Italy, introduces the concept of 'Reverse Inclusion'. Showing how the purposeful recruitment and encouragement of 'gifted and talented' students within the Engineering Classroom can raise standards across the whole cohort this paper questions then very meaning of 'widening participation'.

A shift in focus towards assessment in large group settings is presented in the final paper in this section. Sajjid et al, University of Glasgow, discuss the challenges associated with providing high quality feedback to large groups of engineering students suggesting that the use of 'cluster feedback' can be both efficient and effective for students and academics alike.

Last in this section is the work by Wood & Xavier, Swansea University, explores the application of VR to Engineering Education. Highlighting the importance of immersive technologies in replicating 'real-life' scenarios.

Paper 1: Monitoring attendance and its impact on Engineering students.

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KEY WORDS: Attendance monitoring, degree outcomes, engagement, learning analytics, engineering education.

SUMMARY

This paper presents the findings of a two-year study with foundation (level 3) student attendance and performance. Learning analytics has become a popular term within higher education and there are several dashboard applications available for institutions to invest in. There has also been an increase in attendance monitoring activity across the higher education sector. Some dashboards merge attendance monitoring with other learning analytics data to provide reports and in some cases encourage better engagement by students. The drivers and outcomes linked to such monitoring may be different in different institutions. At Portsmouth, the School of Engineering developed a bespoke in-house attendance monitoring system and has been carrying out research looking at the benefits of such a system for staff and students. Quantitative data was used from the attendance monitoring system along with course specific data collected in previous years before the introduction of the system to evaluate progression. This paper highlights some challenges faced during the implementation of the attendance monitoring trial system with the School of Engineering and presents some observations on the effects that attendance monitoring had on the progression and achievement of students.

BACKGROUND / CONTEXT

The School of Engineering at the University of Portsmouth collected student attendance information by either a roll call or by passing around a sign-in sheet during lectures. This activity was historically initiated by academic staff, sometimes in an attempt to encourage students to attend. The rationale behind this was a belief that if students were aware their attendance was being monitored, then they would be more likely to turn up, and if they were present, they would be more likely to learn. This viewpoint however, has never been universally accepted or agreed (Muir, 2009; Marburger, 2006; Massingham & Herrington,

2006), and so there was a reluctance to pursue formalised attendance monitoring. With the introduction of UK border agency Tier 4 Sponsor licences in February 2009, and the associated monitoring requirements, there was a fresh interest in formalised attendance monitoring. Manual, paper-based attendance monitoring methods were reported as being time consuming and tedious for students and staff alike. The accuracy of paper registers, especially where students were only required to tick against their name, was questionable. A University of Portsmouth learning and teaching grant was awarded in 2015 to investigate the use of electronic systems to monitor attendance and the results are presented in this paper.

AIM AND OBJECTIVES / RESEARCH QUESTION(S)

The prototype system aimed to evaluate:

1. The speed of the registering process.
2. The accuracy of the register data collected.
3. The student and staff experience.

Through selecting a well established course, this research also aimed to observe if the introduction of full attendance monitoring had an effect on either student progression or achievement, by using metrics measured in the course Annual Standards & Quality Evaluative Reviews (ASQER).

This study investigated the use of a prototype electronic attendance monitoring system to establish if it would be beneficial to use such a system, throughout Portsmouth University.

RATIONALE

Several studies have shown a link between performance and attendance and or engagement in class. The School of Engineering felt the need to create and evaluate an in-house attendance monitoring system to investigate the effects of such a system to student experience and attainment. This study investigated the speed of registering, accuracy of data and the staff and student experiences in the implementation of a prototype electronic attendance monitoring system. Observations regarding changes in performance metrics based on the presence of the attendance monitoring system were obtained from historic and current ASQER reports.

The authors believed that there could be benefits from the implementation of an attendance monitoring system through increased student attendance.

Level 3 Foundation Students were academically the weakest of all entry level students and therefore had the most to gain. Trends within the data provided important indicators and previous correlations between the student attendance data over the period of the study and their outcomes can suggest links between the two. A Google form survey was used to obtain feedback from staff and students involved in the trial. The speed of the registering process, accuracy of the register data collected and student and staff experience were evaluated.

The findings presented here may be useful for other engineering schools who are considering implementing attendance monitoring.

LITTERATURE REVIEW

The higher education sector has seen an increase in attendance monitoring activity (Tickle, 2015). With the data available, decision making algorithms (Haddad et al, 2018) and AI techniques can provide useful analysis. Some dashboards merge attendance monitoring with other learning analytics data (Sanders and Bergasa-Suso, 2010) to provide reports and in some cases encourage better engagement by students.

Several review studies have highlighted the complicated nature of investigating a link between attendance and student performance and achievement across different subject domains (Dollinger *et al*, 2008; Schneider and Preckel, 2018; Credé *et al*, 2010). Studies often have struggled to separate the effect of indirect variables, such as intrinsic motivation, prior performance and preparedness on attendance and student performance (Schneider and Preckel, 2018). Instead of conceptual segregation, Stajkovic *et al* (2018) stressed the importance of an integrative approach to understanding student performance as they linked it to the “big five” personality traits and self-efficacy. A systematic review of meta-analyses linking student achievement with 105 variables was carried out by Schneider and Preckel (2017). They ranked all the correlations of student achievement from 38 meta-analyses involving nearly 2 million students. At the top was instruction methods that use peer-assessment and attendance as an antecedent was at 6th position in their ranking based on its effect size. Schneider and Preckel (2017) noted that there have been no controlled studies looking at the impact of mandatory attendance on students performance so far.

Schneider and Preckel (2017) highlighted limitations in research studies in terms of the large Confidence Interval (CI) sizes noted and or Heterogeneity in the results that was not explored, meaning that this is a complex area needing more research. Instruction styles that used social interaction had the most frequent high positive effect sizes. This included lectures, small group learning and project based learning as long as they could balance

teacher-centric and student-centric instructional elements (*ibid*). In other words, what the teaching staff and students do in class impacts the interrelationship between attendance and student performance. For example, proponents of classroom response systems (CRS) and peer-instruction claim that using it enhances students performance highlighting socio-cognitive benefits of the interactions between students and with the teaching staff (Balta *et al.*, 2017).

Overall, many studies conclude that there is a correlation between attendance and student performance (Anikeef, 1954; Garther and Manning, 1998, Newmann-Ford *et al.*, 2008, Lockwood *et al.*, 2006 and Credé *et al.*, 2010) but there are some that report opposite and or mixed findings too (Hammen and Kelland, 1994; McCarey *et al.*, 2007; Rodgers, 2002; Grabe, 2005). Credé *et al.* (2010) carried out a meta-analysis of studies ($K=68$) that studied the correlation between attendance and student performance and found a strong correlation ($\rho=0.44$, $N=21,164$), however, the relatively large 90% Credibility Interval (0.26, 0.62) suggested the presence of moderator variables. Mandatory attendance has been shown to be effective here (Cohn and Johnson, 2006) but authors have shown that not attending a one or two sessions is not as detrimental as not attending majority of sessions. Monitoring attendance and identifying 'at-risk' students in order to prioritise the support provided to such students is another dimension that has gained recent attention, although very few studies have shown positive impact (Larrabee *et al.*, 2018; Tickle, 2015).

Within engineering education, a range of studies show a positive correlation between attendance and performance (Purcell, 2007; Nyamapfene, 2010; Obeidat *et al.*, 2012; Laguador, 2013; Moldabayev *et al.*, 2013; McCool *et al.*, 2015). However, these don't always report that such a correlation is significant. Purcell (2007) showed at 68% average attendance, a strong correlation between attendance at lectures and student performance exists. Obeidat *et al.* (2012) analysed the relevant data statistically and proposed some reasons for this affect including additional information given in lectures that is not present in power-point slides posted online as a tactic used by some staff. Moldabayev *et al.* (2013) presented data on 14 modules with correlation coefficients ranging from -0.048 (Fluid Mechanics) to 0.597 (Introduction to Civil Engineering) with only 3 modules above 0.30 value. Here only 9 modules had significant positive correlation between attendance and performance irrespective of strength. A major shortcoming in almost all Engineering Education Research studies is that there are very few studies that study other factors that may affect performance alongside attendance or designs with control built in them (McCool *et al.*, 2015). Other limitations in this literature include incomplete attendance data (Romer, 1993) or self-reported absences (Durden and Ellis, 1995) and limited sample size (Purcell, 2007; Nyamapfene, 2010). Since engineering education makes use of project based learning where students may engage in peer interactions and assessment, the data on attendance to events where the balance between teacher-centred and student-centred approach is optimal can lead to interesting findings. This study is unique as it does not evaluate or use a commercial system to monitor student attendance and one where student

support is also monitored and it explores benefits other than already established effects on student performance.

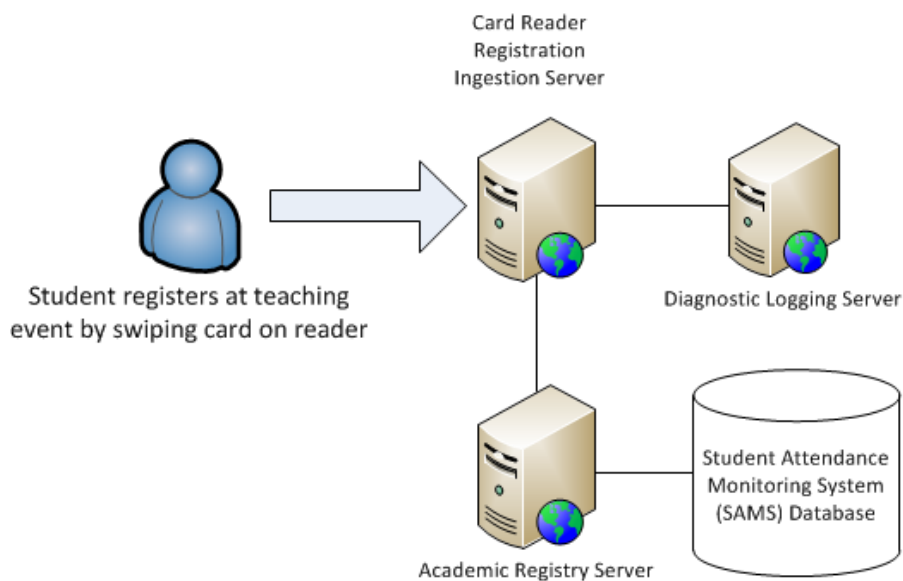
METHODOLOGICAL APPROACH

Electronic card reader hardware was purchased and installed in selected rooms in the University as part of a University learning and teaching grant. These were TCP/IP, Ethernet-based RFID terminals for contactless smart cards, which used Power-over-Ethernet and eliminated the need for external power supplies.

The card readers operated as standalone HTTP web clients. When a contactless card was detected by a reader, it sent a HTTP GET request to the web server. The server responded with standard HTTP reply to the reader. The content of the response controlled the sounding of a beeper and illumination of LED indicators on the device.

Students would register at events by scanning their cards on a card reader. Bespoke software was created to form an ingestion server, to handle the registrations data from the card readers and interface to the University corporate systems (Fig 1). The ingestion server, which was setup for the trial, would receive and capture registration information from card readers and ensure a timely response to the card readers.

Fig 1. Prototype card reading system used in the attendance monitoring trial.



Academic staff were asked to use the electronic card readers to assist with taking class registers. Students were asked, by academic staff, to present their cards to the electronic reader on entry to a classroom. At the end of the study staff and students were asked to complete a questionnaire about their experiences. A participant information sheet was provided to staff and made available to students participating in the electronic card reader study. Taking part (ie using electronic card readers) was voluntary. Students however were required to participate in the universities student attendance monitoring, and although participation in the electronic card reader registration was optional, there were alternative means for students to register their attendance at the selected sessions. Students were able to opt-out by simply not presenting their card to the electronic reader. Participation in feedback was also optional and anonymous.

A trial group of academic staff and students including (but not limited to) Level 3 foundation students were selected for the study and asked to use the electronic card readers to register student attendance at compulsory events.

A Google form survey was used to obtain feedback from staff and students involved in the trial. 60 members of academic staff who had indicated that they were willing to be a part of the trial were emailed the staff feedback questionnaire and 42% (25) responded. Students who had used their cards to register for six or more events were selected to participate in the student feedback questionnaire, and these 3367 students were emailed the survey, of which, 16% (532) responded.

This study compared the progression rates of students onto M level degree programs to historic data collected when the same cohort of students were not having their attendance monitored.

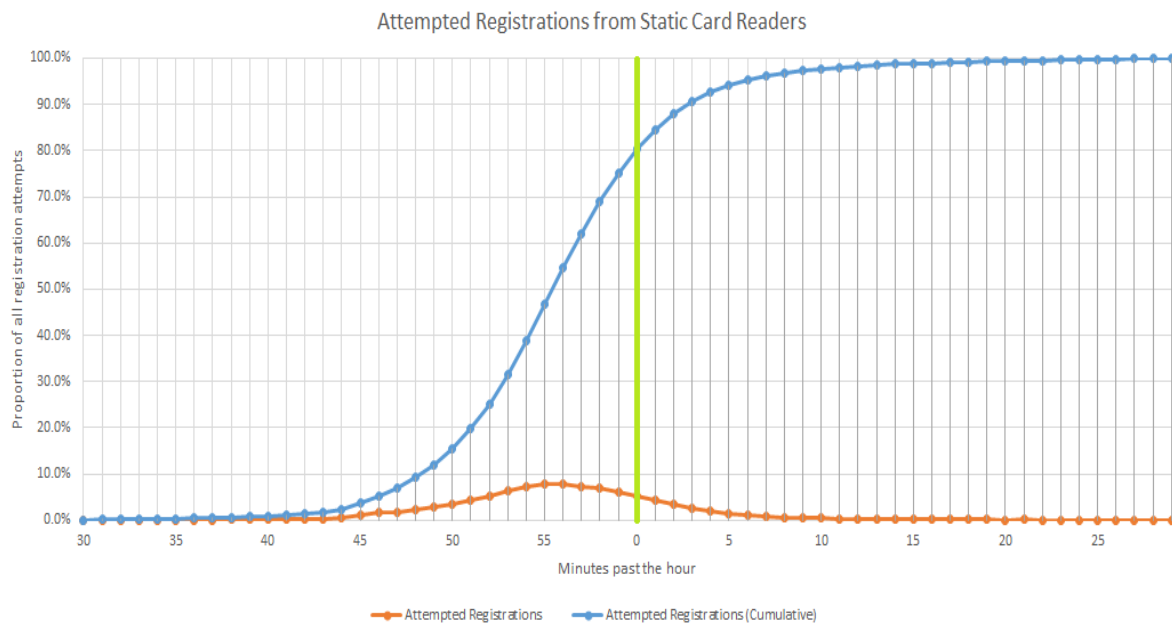
KEY FINDINGS

The key findings can be split into four areas; the accuracy of the register data collected, the student & staff experience, the speed of the registering process, and the effect on either student progression or achievement. This paper presents the latter two findings (the speed of the registering process and the effect on either student progression or achievement).

The speed of the registering process was assessed through analysis of diagnostic logging data from the card reading system and through specific questions in the staff and student survey.

The diagnostic logging system recorded the time at which students registered and it was therefore possible to plot the time at which students registered with respect to the timetabled start time for events. The graph in Fig 2 shows that the highest throughput of registrations occurred at five minutes before the start time. At the start time, 80% of students had already been registered.

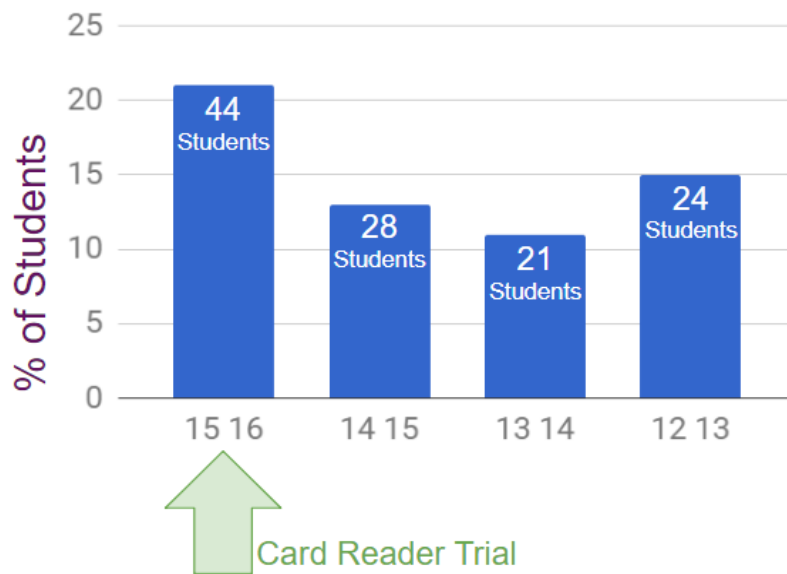
Fig 2. The normalised proportion of all registrations plotted against lecture start time.



All staff except one responded that the card readers never cause students an unacceptable delay in entering the classroom. The single member of staff who responded that sometimes there were unacceptable delays, noted in the free text field 'Delays were only early on. Students got used to it quickly enough and then it worked smoothly'. 56% of students never had any unacceptable delay in entering a classroom, 38% reported delays sometimes and 6% reported that they were always delayed.

The effect on either student progression or achievement was measured by using metrics taken from the Course Annual Standards & Quality Evaluative Reviews (ASQER). The data showed that there was no significant change in the student progression statistics (i.e. the same percentage of students were failing or repeating the year) for the year where students attendance was being monitored compared with the previous three years.

Fig 3. Showing the increase in the percentage of Students progressing to integrated Masters Degrees during the Card Reader Trial (15-16) and in the preceding three years.



However, the study found that students who were potential high performers benefited from attendance monitoring in terms of better achievement and were more inclined to transfer to MEng courses. To do this, students needed to achieve an average mark of 70% in all modules and in the past, when the monitoring was not present, fewer students were eligible to progress to MEng courses. However, with attendance monitoring there was over 75% increase in the numbers transferring to MEng courses, that is 12% to 21%. (Fig. 3)

DISCUSSION

A trial card reading network was created and evaluated to investigate the effects of such a system on student experience and attainment.

The project investigated the use of electronic card readers and identified ways in which they could interface with existing University systems.

The study concluded that the introduction of an electronic card reader system at the University of Portsmouth would not cause unacceptable delays for students entering classrooms and would contribute positively to student experience.

Results from this study indicate a correlation between the practice of monitoring attendance and an increase in performance of students with the potential to perform well. The study could not find any correlation between the introduction of attendance monitoring

and increase in student progression/retention for the level 3 engineering students involved in the study. The data from attendance monitoring system is now available to personal tutors as well as to students from the university's new personal tutoring platform as well as from student portal. This was not the case for this study however. Although not the focus of this study, the data may in future influence student behaviour, either when used by the students themselves or by their personal tutors to discuss and influence attendance patterns.

It is acknowledged that other factors may affect these results such as changes in teaching or course material, however this cohort was selected because the course was well established and the modules and teaching teams has remained consistent for a number of years, thus minimising the possible effects.

The findings may be useful for other Engineering Education schools who are considering implementing electronic attendance monitoring.

CONCLUSIONS & RECOMMENDATIONS

The project investigated the use of electronic card readers and the effect this has had on foundation-engineering students' attainment and student experience. The study recommends the introduction of attendance monitoring systems since students who are potential high performers have benefited from attendance monitoring in terms of better achievement. The study concluded that the introduction of an electronic card reader system at the University of Portsmouth would contribute positively to student experience.

During this study there was no feedback to students about their attendance, which was recognised as being a weakness. A strong recommendation would be that all attendance data collected about a student is made visible to them. This would allow better verification of the data collected (as students could complain if it was incorrect) and would provide students with important feedback about their attendance, which again might encourage improved engagement. Additionally, personal tutors may be able to influence change with access to this important set of data.

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Paper 2: Using Collaborative Online International Learning as an Approach to Promote Curricula Internationalization in Engineering

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KEY WORDS: students, engineering, collaborative, cooperative, internationalization

ABSTRACT

A Collaborative Online International Learning (COIL) learning activity was carried out for undergraduate students in mechanical engineering in three different Universities, Scotland (Host institution), Spain and Venezuela, in order to give students, the opportunity to prepare themselves for a global society

BACKGROUND / CONTEXT

As academics it is important to prepare our students for a global society, where social, cultural and economic roles play an important aspect; where the value of internationalizing our curricula will provide students with international and intercultural skills. Online collaboration is one approach to internationalising the curriculum (Green, 2015), an important aspect in promoting intercultural competencies, international perspectives and ethical sensitivities, which may contribute to the enhancement of students' capability to develop as responsible global citizens (Leask, 2015). By incorporating e-learning activities in our teaching we also provide students with the opportunity to interact and engage with peers in cooperative and collaborative learning (Bach et al. 2017), helping preparing them

for a digital future as well. Online discussion forums and wikis are used for collaborative and cooperative learning and have been widely used to promote student's engagement (Cole, 2009 and Muñoz-Escalona, 2017, Muñoz-Escalona, 2018).

International facts and Figures provided by Higher Education (HEA, 2017) show that the UK is the second most popular destination in the world for international students (12.5%). The United States is the most popular with 24.6% and Australia the third most popular with 7.8%, Despite numbers have increased in 3% for the UK since 2014 the figure is still low. High investment and efforts have been conducted for Internationalization of the Curricula where approaches such as distance learning, blended learning, Massive Online Open Courseware (MOOCs), can be mentioned, however research still shows that around 80% of European students will not be able or willing to study abroad (Green, 2015), while 78% of undergraduate students recognise that studying with international peers prepares them to become global citizens (HEA, 2017).

LITERATURE REVIEW / RATIONALE

In 2009, Leask cited the internationalisation of the curriculum (IoC) as *"the incorporation of an international and intercultural dimension into the content of the curriculum as well as the teaching and learning processes and support services of a program of study"*. Thus, the curriculum itself is viewed as the vehicle through which students can obtain an international experience through their curricula, for their development of intercultural competencies and capabilities during their studies. Moreover, as the Higher Education Academy (HEA) suggest, an internationalised curriculum should prepare students to be able to effectively *"contribute responsibly to a globally interconnected society"* in addition to providing *"high quality, equitable and global learning experience for all students studying UK HE programmes, irrespective of their geographical location or background"* (HEA, 2014).

An internationalised curriculum is one that help students develop *"graduate capabilities, global citizenship and intercultural competency"* (Leask, 2015). As academics we must try to ensure that our students gain the confidence and capabilities to function effectively in a 'supercomplex' globalised, market society (Barnett, 2004). In 2005, Robson suggested that academics establish international and intercultural learning outcomes in aiming to influence students learning in this area, which is also reinforced by teaching and relevant methods of assessment.

Therefore, IoC is not solely about the generation and inclusion of extra content in the curriculum, it is more concerned with the greater alignment of learning outcomes and possible use of Internationalised Learning Outcomes (Beelen and Jones, 2015) in recording what, when and how students develop in regard to graduate attributes, intercultural competency and global citizenship in their programme of study.

The low uptake of physical, outward bound international exchanges by students in the UK (15, 610 in 2013/14) and more markedly in Scotland (2,107 in 2013/14) versus nearly double the number of incoming students on Erasmus exchanges (European Commission, 2015) provides a clear rationale for considering alternative means to facilitate international experiences for students and viewing the curriculum as a focal point for these. Collaborative Online International Learning (COIL) provides a way to engage students in a near replicable experience to their peers that undertake an Erasmus exchange.

Furthermore, COIL is viewed *“as a means to internationalize curricula, build global partnerships, and help prepare globally competent students who are equipped for work and civic engagement in a global context”* (State University New York, n.d.).

COIL projects involve collaboration between two or more groups of students and staff where academics develop a shared syllabus in a subject-area, discipline or topic which relates to existing curriculum and intended learning outcomes, or newly-devised project specific curricula and learning outcomes. Projects normally consist of two or more partner institutions from who approach the project from different cultural and geographic backgrounds and perspectives. Utilising online technologies for teaching and learning - e.g. WebEx, e-mail, Wikis, Virtual Learning Environments (VLEs), Facebook etc. – in either synchronous or asynchronous exchanges, COIL brings a live, global dimension to course context through cross-cultural dialogue and teamwork. As a form of virtual mobility and international exchange between students and staff, COIL can help students develop intercultural communication and other related capabilities, particularly with its emphasis on experiential and collaborative student-centred learning. As a result, COIL offers new, alternative lenses for students and staff to view their own culture, subject area and professional practice, which enhances student’s digital literacies and ability to work collaborative as part of a group in real-life setting, further promotes their employability beyond graduation.

Whilst undoubtedly not as rich or as intense an experience as a physical international experience living and studying in another country and culture, COIL provides an accessible,

cost-effective intercultural experience which complements and supports related aspects of students' development during degree study, e.g. team work, empathy, collaboration, communication etc., and is available to all students.

The purpose of this research is to give students the opportunity to work with international peers, exchange knowledge in the area, increase communication skills, experience different culture and innovating and enhancing their practice through the effective use of digital and collaborative technologies - allowing them and invited academics to potentially establish their own COIL projects as a result.

AIM AND OBJECTIVES / RESEARCH QUESTION(S)

This study aimed to:

- Promote and encourage intercultural competences, international; perspectives and ethical sensitivities among students to become responsible global citizens.
- Encourage and enhance knowledge exchange, communication skills and teamwork.
- Promote global manufacturing awareness in engineering students.

METHODOLOGICAL APPROACH

A COIL activity was conducted in three different institutions for 2nd/3rd year of undergraduate engineering degree taking materials and manufacture subject or equivalent. Table 1 show Countries involved and number of participants.

For the activity a “car dissection” was selected, where different aspects were analysed and discussed:

- i) Functionality of the car component selected for study
- ii) Physic involved
- iii) Materials (Analysis of microstructure)
- iv) Manufacturing process

Table 1. Countries involved and number of participants

Country-University	Degree	Male	Female	Total
Scotland (Leading institution)	2 nd year Mechanical engineering	43 (1 international, 1 Erasmus)	3 (2 Erasmus)	46
Spain	Industrial Design Engineering and Product Development degree	5	6	11
Venezuela	3 rd year Mechanical Engineering	16	9	25

The activity took place over a period of 3 weeks which included e-learning tools to develop, communication, collaborative, cooperative and teamwork skills. The activity was divided in four main stages:

- i) Introduction with their peers (social forum)
- ii) Asynchronous online discussion forums (ADF) to discuss and analyse the selected component
- iii) Wiki to upload and edit the important findings (registered in the discussion forum)
- iv) Development of an A3 poster to communicate and share their findings with other class mates

ADF was selected due to its effectiveness, as they can be access anytime (different time zone) and all posts are registered (Ellis, 2008)

The wiki was used as a tool to develop a poster as the final outcome of the major findings of each groups' discussion (Ramanau, 2009, Cole, 2009 and Lai 2011))

Students were divided in groups of 7-9 students based on three aspects.

- i) At least one student from each participating institution in each group (this aspect restricted the amount of groups to 11 as there were only 11 students from the Spanish institution).

- ii) Students level of English (only restricted to students from Spain and Venezuela)
- iii) At least one female student per group, for equality and diversity purposes.

Moodle was selected as the Virtual Learning Environment as this was the platform used by the Scottish hosting institution.

It must be highlighted that 90% of the participants had no experience using online discussion forums and/or wiki as e-learning tools. Spanish students were familiar to Moodle, as it was the VLE used in their institution; however Venezuelan students were not familiar with this VLE.

Once the activity was concluded a questionnaire (survey) was distributed to all participants in order to collect information regarding students' experience. For a deeper analysis a one-hour focus group was conducted at each university with 10-12 volunteers. The questions asked in the focus group followed the Model AIDA (Awareness, Interest, Desire, Action). A qualitative approach was used to analyse the results from the survey and the focus group.

KEY FINDINGS

- The majority of the students described the activity as different, interesting, innovative, unique, challenging and motivating.
- Students from Spain and Venezuela felt that their confidence increased 40% and their communication skills 60%.
- Overall all students felt that the activity increased their confidence communicating with other cultures in 85% and 70% have a better understanding of a different culture and country.
- 65% of the students have increased their likeability to travel.
- 70% of the groups were led by the Venezuelan students.

DISCUSSION

A social forum was provided for the students to virtually meet their groupmates. It was observed that students from Spain and Venezuela took the initiative to start the conversation and comment about their hobbies, preferences, etc. and students from Scotland took more time to post (initial observers). When analysing the data, it was thought that this behaviour was probably due to the fact that students from Spain and Venezuela

were in their 3rd year of studies compared to students from Scotland which were in their 2nd year, however when analysing the data (25% of students from Scottish institution were mature students with ages between 25-40).

73% of the students responded that now they feel more comfortable and capable of finding jobs abroad as the activity was used as a benchmark and they were able to compare and share their knowledge with international peers. Students also realised that by interacting with international peers they were having a taste in global manufacturing; i.e.

“Great experience as we had to work with students from different countries, just like in real life as in the future most of the companies will be global and we will need to work with colleagues from around the world in a project”.

Some students also realised that despite all students were undertaking an engineering degree there were differences in communication styles as steels were named differently (code/Standards); i.e.

“I felt confused with the name my international peer was giving to the steel we were analysing. I thought it was because of English barrier but then I realised he was right, and he was just using an American Standard and I was using European Standard”.

In general, the activity was found to be challenging and time consuming, however very rewarding. Overall 93% of the students were satisfied with the whole experience. Students enjoyed the activity and they felt their level of knowledge and understanding of the topic has increased. 90% of the students enjoyed interacting and working with students from other institutions or from abroad

83% of the students will recommend the activity to other academics. This difference of 10 points between satisfaction (93%) and recommendation (83%) was basically due to the fact that students recognize that the activity was challenging and time consuming and sometimes difficult to interact daily due to commitments with other subjects.

As all activities the weakness point was addressed to long periods of lack of interaction or participation of some of the students.

The long periods of lack of communication were due to

- students not subscribing to automatic notifications from the forums,
- Different time zones
- Commitments with other modules
- lack of knowledge in use of e-learning tools and the use of Moodle as VLE platform.

Despite all efforts it was very difficult to arrange a suitable time to satisfy all students from the three institutions to conduct the activity,

CONCLUSIONS & RECOMMENDATIONS

- Collaborative Online International Learning has proved to be an excellent and engaging educational approach to be used for internationalizing the curricula.
- Students participating in the COIL activity recognize the value and the importance to interact with international peers in order to get ready for a global environment.
- Academics involved
- Students have seen the activity as an opportunity to enhance their CV by undertaken an international collaborative activity for their first time.
- 90% of the students felt they have benefit from the activity as they were able to enhance their communication skills, team workability and experience interaction with international peers.
- 83% of the students will recommend the activity, however it was perceived as very challenging and time consuming.
- Despite it is recognised that COIL will not substitute the experience of living abroad, it can provide a taste and mind opener to think in future international opportunities
- It is recommended to upload a video on how to use the different e-learning tools and VLE platform rather than provide them with documents to decrease student's anxiety towards the use and application of e-learning tools

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Paper 3: Using learning analytics to improve the design of remote practical activities in Engineering

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KEY WORDS: Learning Analytics, Remote Labs, Electronics, Learning Design

SUMMARY

Distance learning universities face the challenge of offering practical activities as equivalent alternatives to those offered by conventional universities. In particular, Science and Engineering require laboratories to provide students with practical experiences that consolidate the learning acquired through other learning materials such as websites, text, videos, podcasts, conferences, and online tutorials.

In this paper we consider The Open University *distance learning* course “Electronics: sensing, logic and actuation” which makes use of hands-on experiments for its sensing, logic and actuation components, *without requiring the students to attend an on-campus teaching lab*.

Now we are in the process of gathering both quantitative and qualitative evidence to evaluate the educational effectiveness of our remote-access “Open Engineering Lab (OEL)” to inform the design of new modules planning to use the OEL. Quantitative data are used to understand students’ interaction with the on-line activities while qualitative data provide a view on the students’ perception of the experience, including those who did not engage with the experiments.

This is aligned with the University’s “Analytics for Action” process, aimed to provide relevant data and support to module teams at the earliest opportunity.

BACKGROUND / CONTEXT

Since its beginnings, The Open University has explored different ways to provide its students with the practical experiences required to offer a high quality student experience in STEM subjects. Returnable and non-returnable home experiments kits were distinctive features of some of our modules in the past. The costs of provision/maintenance of up to date kit, warehousing and distribution, together with operational experience and the challenges of health and safety compliance have made this option unattractive. In the meantime the technological opportunities of the internet have enabled remote access to actual state-of-the-art lab equipment with the potential to increase accessibility and usage.

The Open University has been using online instruments in distance learning programmes in Science since 2009. The 300 study-hour module *“Electronics: sensing, logic and actuation”* was the first Engineering module to use remote experiments as a key component in its learning and teaching strategy.

As well as being able to implement systems that work, an essential practical skill for the engineer is to reason why things go wrong, and to devise and test solutions - Lab experience and access to specialised equipment is often regarded as an important factor in employability. Computer simulation for student experimentation can be very effective; normal behaviour and fault conditions or component failure can often be convincingly modelled. However, the frisson of reality allows students to experience the complexities of ‘unforeseen’ circumstances and behaviours; many electromechanical systems and sophisticated circuits may be easier to construct and test than they are to model.

The accelerated progress of internet technologies has made it feasible – and relatively affordable – for distance learning Universities to provide real, remote lab experiences to students, using remote access connections, livestream video and archival data as an online resources for practical hands-on experimental work. Since students’ interactions are via the internet there is direct access to analytics that characterise student activity.

Our module was the first to use real equipment in the newly built remote OpenEngineering Laboratory wing of the online OpenSTEM Labs (2018), established in 2016/17 as part of a STEM Capital investment jointly funded by HEFCE and The Open University. The hardware for the experiments is housed in rack-mounted bays about 600 x 500 mm with web-cams enabling students *to see and hear online in real time* what is happening. Students can exercise real-time control of this equipment through a browser-linked graphical user

interface on their home PC, graphics tablet or mobile phone. An integrated online booking system allocates students to one of the equipment bays for each experiment.

“Electronics: sensing, logic and actuation” uses a range of traditional and digital media including Print, the OU’s Virtual Learning Environment (VLE), the National Instrument’s Multisim Live circuit simulation system, and the OEL with its specialist hardware and software. We faced the challenge of delivering content through multiple platforms, while keeping the navigation clear and workloads at manageable levels. Online experiments in this module for the OEL were based on National Instruments ELVIS boards (below termed ‘Workstations’). Examples include a driven pendulum, a spinning disc light chopper, a logic gate matrix and a motor and actuator test bed, among others.

Many other Engineering modules currently in the pipeline are planning to include the use of the Open Engineering Labs as a key component of their learning and teaching strategy. Some of those modules are also considering the inclusion of Lab work in their assessment strategy. Our aim was to learn from this ‘path-finder’ experience to improve the design of future OEL experiments. The OU reviews all its course modules after their first presentation to consider how to improve the module and disseminate good practice for other module teams. Since 2016 learning analytics data have been collated and analysed as part of the process. This paper reports work undertaken in this overall context.

LITERATURE REVIEW

Laboratory work in engineering education is valued as a vehicle for integrating theory with practice, for learning through inquiry, for experiencing aspects of professional practice and for collaborative working (Edward, 2002). The interest for virtual and remote labs (VRLs) in education has been growing steadily both in number of papers and in citations since its beginnings more than 20 years ago and across a variety of educational environments (R. Heradio *et al.*, 2016). VRLs are found to be cheaper and to provide additional benefits when compared with ‘traditional’ labs. These benefits include increased availability and accessibility (can be used from anywhere at any time), observability (performance can be monitored and logged and sessions can be recorded) and safety. (Gravier *et al.*, 2008). VRLs are also reported to deliver equal or higher student learning outcome achievement than traditional labs (J.R Brinson, 2015; Brodeur, 2016).

While VRLs are clearly a feasible option to teach through practical work to distance learners, we need to continuously improve the design of the remote labs activities to make best use

of available technology. We need also to be mindful of the direct impact of Learning Design on student outcomes (Rienties *et al.*, 2017).

Learning Analytics have been used in some VRL environments to provide educators with information regarding students' online engagement, including the results of their experimentations and their contributions to forums. This offers a level of support adapted to student proficiency (Tobarra *et al.* 2014). Learning analytics can also be used specifically to identify student difficulties in learning with VRLs (Jona & Uttal. 2013).

AIM AND OBJECTIVES / RESEARCH QUESTION(S)

The existing literature suggests that there is plenty of evidence on the advantages in the use of VRLs. However, as the supporting technologies change and evolve very fast, we need to understand the factors that makes a VRL experience a pedagogic success.

Our major objective is then to answer the research questions:

- How can we improve our understanding of the factors that make an OEL experiment successful, through the systematic analysis of the available data on usage?
- What variables do we need to measure to monitor the efficacy of these remote labs?

METHODOLOGICAL APPROACH

Our rationale was that by gathering and analysing the data as soon as they became available, we would be in a position to provide advice to the Module Team in a timely manner, for them to introduce evidence-based changes to the current design (pedagogical and functional). Such advice, properly shared with other module teams currently in the development phase would be of wider benefit.

Since our module (*Electronics: sensing, logic and actuation*) was the first to use the OEL in a fully interactive format, we wanted to understand what makes a lab experience successful in terms of student engagement and delivery of learning outcomes. We are particularly interested in the part the OEL work has in leading to higher rates of retention, completion, success and satisfaction.

Usage-data were collected throughout the different phases of the module's production and presentation cycle.

During the development phase of the module, a sample of the content went through a formal developmental testing process, which provided initial data to test and improve the design and usability of the experiments including the expected workload. Based on the findings of the developmental testing, the module team took the decision to remove one of the planned experiments, in order to reduce the student workload.

During the production phase of the module data related to the estimated workload were carefully monitored and compared with University guidelines and the findings of the developmental testing exercise.

During the first presentation of T212 we collected and analysed data from five main sources:

- the OU data warehouse, in particular Student Progression Dashboards (student profile, engagement with the VLE content and with specific tools, submission rates and assessments scores, retention figures, concurrency, and qualification profile). The data obtained from these sources were analysed by the Learning Design Team and shared with the Module Team members at three different data support meetings
- the OEL's own data provision showing specific booking and attendance data for all experiments
- a voluntary and anonymous survey, specific to the OEL experiments, using an existing tool embedded in our VLE
- spontaneous students comments on the online conferences (forums)

The quantitative data were used to understand students' online behaviour and their interaction with the different online tools, either within the VLE or with the OEL experiments.

The qualitative data helped to understand the students' perception of the experience, even from those who did not engage at all with the experiments. Qualitative data analysis provided additional depth for the overall evaluation of the student experience. In particular correlations were sought between student activity and quantifiable outcomes such as assessment scores.

As the first cohort ($N=123$ students) was relatively small by Open University standards, the data were analysed manually by the authors, and shared with the module team members.

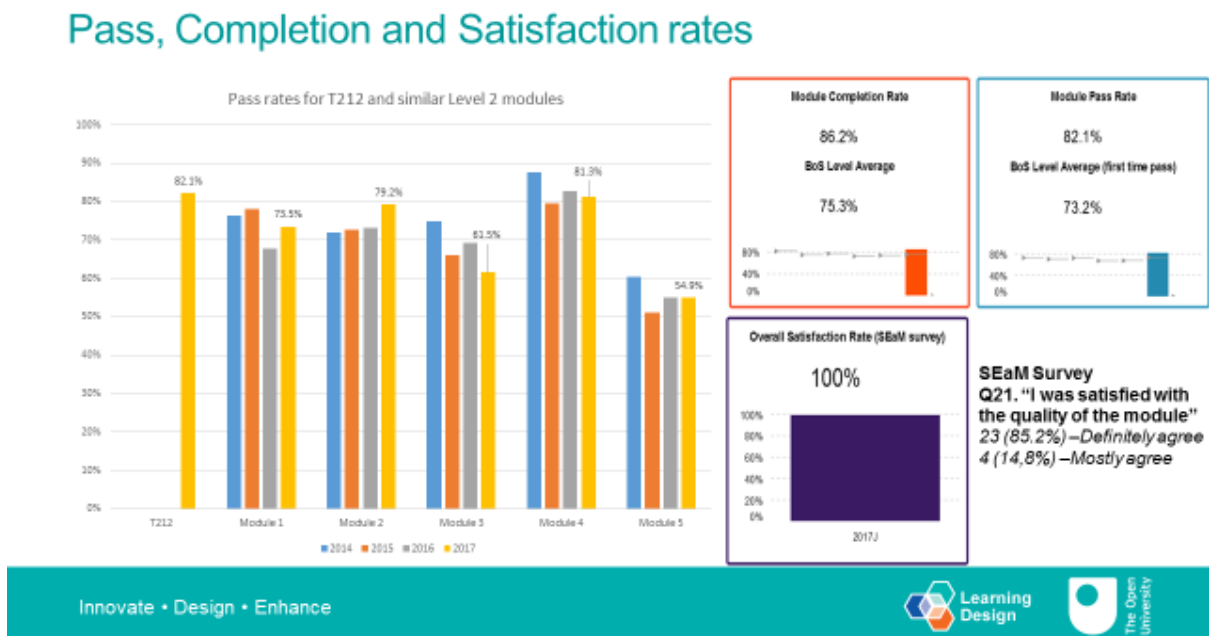
The results of the analysis of the data were widely shared by the Learning Design Team through its work with diverse academic production teams at different stages of the production process.

KEY FINDINGS

The module's overall performance was remarkable, with a 100% satisfaction rate among students in the formal end of module survey "*Student Experience on a Module*" (SEaM). "*Electronics: sensing, logic and actuation*" also achieved the highest completion and pass rates of comparable modules at the same level in the October 2017 presentation, and one of the three highest of the last 4 years (see Figure 1).

Formal retention was also very high as fewer than 9% of students withdrew from the module. This was the lowest withdrawal rate for all comparable modules for that year. The average withdrawal rate for all other modules used for comparison was 20.1%. Moreover, there was no pattern in the timing of the withdrawals, suggesting that the small number of withdrawals seem to be due to personal circumstances (most OU students are part-time) rather than to fundamental learning design issues. Assessment submission rates were also higher than comparable modules.

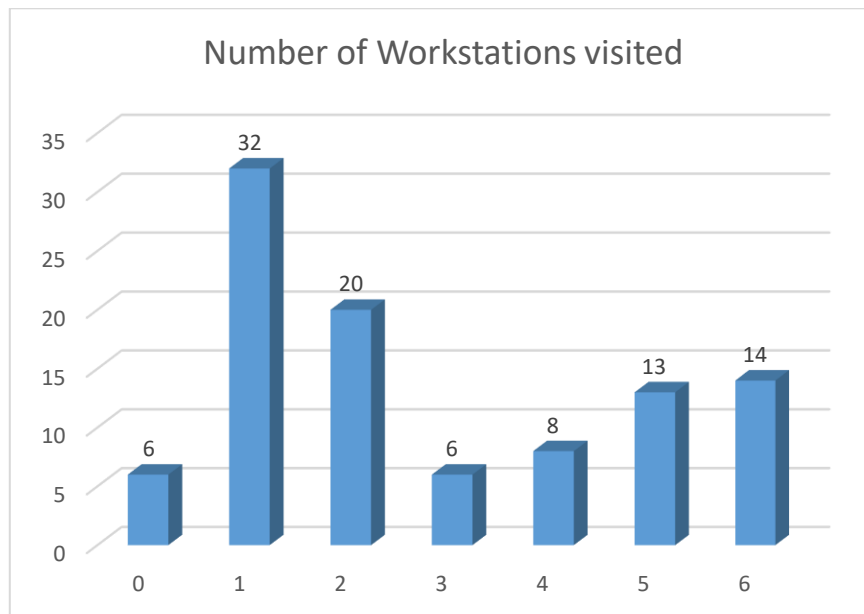
Figure 1 Cohort statistics for "Electronics: sensing, logic and actuation" (T212 -2017) in comparison with Level 2 comparable modules in previous and current year



Specific data for the OEL experiments (Figure 2) showed that 80% of students engaged in some way with the online experiments, with 76% attending at least one Lab session (*i.e.*

using at least one Workstations) and 22% of students engaged with 5 or more different Workstations. These figures are considered high since the activities were not formally assessed.

Figure 2 Number of students engaging with up to all 6 Workstations for “Electronics: sensing, logic and actuation” (T212 -2017”)



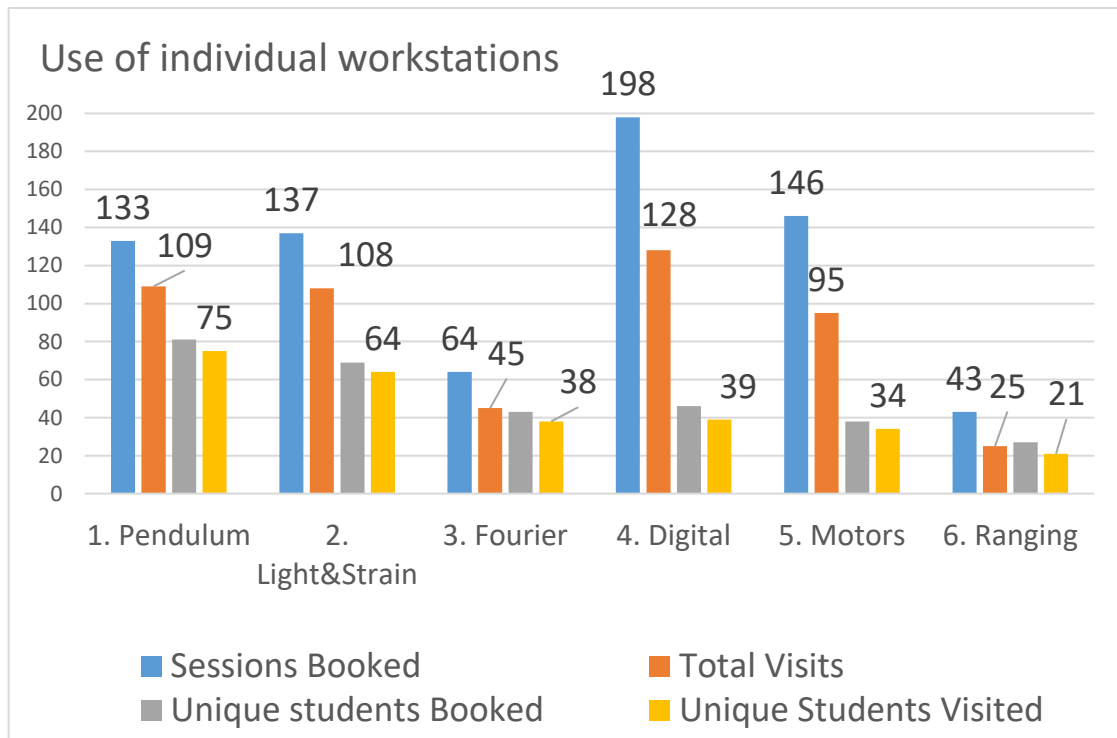
Some experiments attracted more students, while others had a higher proportion of students visiting more than once (see Table 1). Workstations with a single activity resulted in a higher ratio of visits per student per experiment. The scheduling of the experimental work within the study year may have also affected the engagement levels, but note that online access to the OEL experiments was available round the clock with the exception of a 2 h middle-of-night reset window.

The number of students that visited the Workstations declined from 75 (61%) for the first activity (Pendulum) to only 21 (17%) for the last one (Ranging) – see Figure 3. This could be due to the loss of the novelty factor but also could be related to students’ prioritising other activities that have a direct impact in their assessment.

Table 1 Student engagement with Workstations

Workstation	Visits	Unique Students	Number of activities	Visits per student	Visits per student per experiment
Pendulum	109	75	1	1.45	1.45
Light & Strain	108	64	2	1.64	0.82
Fourier	45	38	1	1.18	1.18
Digital	128	39	4	3.28	0.82
Motors	95	34	4	2.79	0.70
Ranging	25	21	1	1.19	1.19

Figure 3 Engagements with each of the six Workstations



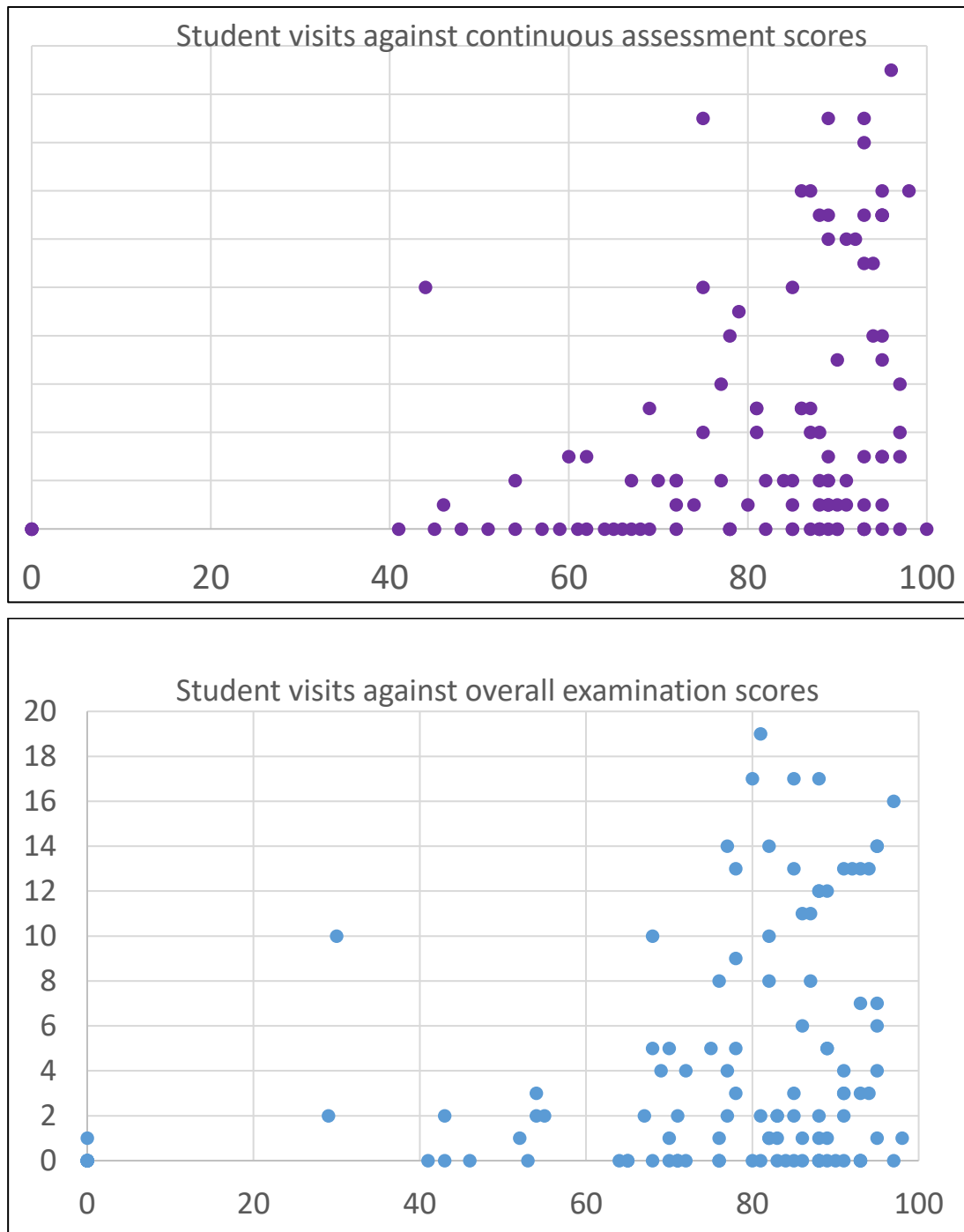
Students that engaged more with the online labs were more likely to obtain better grades, both in the continuous evaluation and the examinable components, although a smaller number of students scored highly without any online lab engagements –see figure 4

Owing to factors beyond our control we only have free text comments from a small number of survey responses (6); these have been conflated with an analysis of traffic on the Virtual Learning Environment (VLE) forum. Together these suggest the following:

- the time students actually spent on the activities was in line with the Module Team plan:
"The experiments were well written and the online lab was allocated enough time for each part"
- students found OEL experiments very engaging:
"The OEL is just awesome, being able to carry out live experiments over the web was a fantastic learning tool" .*"The OEL experiments definitely enhanced the whole learning experience for me"*
- Although not directly assessed, engaging with the experiments helped students to prepare for the assessments:
"The digital experiment really helped me understand what was required for the assessment"
"OEL 4 helped by highlighting the differences between the different types of motor"
"OEL 5 helped in the EMA [End of Module Assessment] by clarifying some aspects of ranging sensors - in particular their suitability for different physical environments"
Students found the experience very hands-on:
"The OEL enabled that physical 'see and touch' and added tremendously to the enjoyment of the module"
- The use of the camera to show the experiments live was highly regarded by students:
"All experiments were set out in a way that made them accessible while giving great visual indications in both real time cameras and in displaying the data"
- Some students found the experiments "too perfect" and suggested that the remote labs experience is not enough for professional practice:
"I would be concerned for any student that based their practical knowledge purely on the results of the OEL, as they may get a nasty surprise when they try and do anything for real"
This comment could represent the view of some of our students that already have access to lab equipment and practical experience. 80% of the students registered for this module were working full time

A few students reported issues due to poor internet connections, particularly with the video. This could be related to students with substandard internet connections at home and were unable to use their workplace internet to study at The Open University: *"The ranging sensor experiment did not work correctly, the video feed was not working so I could not see the sensors moving, etc."*

Figure 4 Correlations of student engagement with assessment



CONCLUSIONS & RECOMMENDATIONS

Engagement figures and feedback from students indicate the *“Electronics: sensing, logic and actuation”* online experiments are a very effective resource for teaching distance learners through practical work. The positive engagement of students with the OEL for *“Electronics:*

sensing, logic and actuation” vindicates the strategy to include OEL activities in all future engineering courses.

Collecting and analysing data as soon as it becomes available enables evidence-based changes that inform and improve design of modules. Systematic and timely review of the available data allows for the continuous innovation and improvement of learning materials and activities, providing opportunities for early interventions. More and better quality data are required for a more thorough evaluation of the educational effectiveness of our online experiments (which is planned). Tutorial guidance or integral assessment may be required to encourage participation. Tools like the VLE In-line (same page) discussion forums may also be helpful and these have been implemented in the October 2018 presentation.

A larger study is required to consolidate the findings reported in this paper. Such a study would include a number of OU courses that have started or will start using the OpenSTEM in their next presentations. Additional data – such as time stamps to indicate student interaction with the experiments – should be collected. The requirement to collect relevant data should be considered at the design phase of courses. Similar experiences from other distance learning organisations could be included in the study.

Though none of our sample data directly relates to accessibility we note that special attention should be paid to the continuous improvement of the accessibility features of the OEL experiences. Accessibility should be considered at the design stages and should aim at providing an inclusive experience, working closely with the institution specialists. Particular consideration should be given to adjustments for visually impaired students as many of the present experiments rely on visual feedback. This approach will also inform the design of valid alternatives for whom the remote labs are not yet accessible.

The authors gratefully acknowledge the work of the OpenSTEM Labs team who established the concept and infrastructure for the OEL.

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Paper 4: Inclusion: a new reverse perspective

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KEY WORDS: inclusion, reverse inclusive process, talented students, protégé students, quality

ABSTRACT

Reverse inclusion has been recently proposed as a powerful tool to pursue many relevant goals at the same time, precisely to assure deserving students higher educational standards and stimuli, to strengthen the initiatives for supporting and including protégé students, to assess new pedagogical methods and teaching contents for the benefit of the whole students' community.

This paper is aimed at presenting and discussing an on-going project carried out at an Italian technical University, the Politecnico of Torino, suffering from a high student to teacher ratio. This problem is mostly imputable to the increasing enrolment of freshmen coming from many different regions and countries, who show varied cultural background and abilities. In the present project, therefore, the concept of reverse inclusion was adopted as the cornerstone of the activities conceived and performed, in order to assure the larger number of students as possible a tailored range of flanking measures. The preliminary results of this experience may represent an empirical demonstrator of the effectiveness of reverse inclusion in the field of Engineering education, as well as a sound tool for mapping the impact and the overall benefits of such approach.

The project has been developed starting from the academic year 2014/15, and it was firstly aimed for talented students, that is to enrich the curricula of the top 4% freshmen, on the about 4500 enrolled each year, with hybrid activities. This was quite easy to do, since all the Engineering Bachelor's degree programmes of our University share a first-year path equal for all the different majors, and the curriculum differentiation progressively occurs during the second year.

However, keeping in mind the objective to develop the project in a real reverse inclusion perspective, the selected deserving students are asked to follow the standard lessons together with all the other students, whereas they were grouped in homogeneous classes only for specific supplementary lectures and laboratories, with the aim of deepening their scientific background, fostering critical thinking, and stimulating interdisciplinary approaches.

Besides the benefits for the deserving students deriving by these talent-oriented activities, two other relevant results were achieved. The inclusion of the motivated talented students for the majority of the regular lectures and inside the standard classes ensured a driving force for the protégé students, who were involved in mixed groups for discussing and studying. This spontaneous inclusion assures them a support in improving their performances, as traceable throughout the analysis of their career. In addition, as the group of talented students alone constitutes a separate class only for additional teaching activities, innovative educational contents and pedagogical methods, as well as reviewed courses were proposed them inside the project. This was used to set up and optimize these experiences before extending them to the whole students' audience.

Preliminary positive achievements are here discussed, based on one complete cohort of students, the first ones include in the project, and partially on the second one.

INTRODUCTION

During the recent past, a growth on the student to teacher ratio has been registered at the Italian Technical Universities, generating a prolongation of the mean graduation time. For example, at the Politecnico di Torino this ratio is 40:1. (Ballatore, et al., 2018). To face this problem the University is strengthening a policy of inclusion towards protégé students in order to guarantee all students to reach an adequate level of knowledge and complete their studies in the due time.

Starting from an analysis of the concept of teaching inclusion in the university, one can see how its recent reversal, which means inclusion and support to the most capable and deserving students for a renewal of teaching methods and contents leads notably advantages to the entire university community and in particular to 'weak' students.

The present paper is aimed to describe the new concept of reverse inclusion and provides some application examples and results. This will be achieved by looking at the impact that the project 'Research among Quality - Young Talent track' ("La Ricerca della Qualità - Percorso per i Giovani Talenti" in Italian;

https://didattica.polito.it/Percorso_per_i_giovani_talenti_en.html) has on the overall community. The project is open to both Engineering and Architecture students, but the

reverse inclusion approach was tested only in the case of the Engineering programmes, for many reasons (the number of students involved, the need of experimenting new pedagogical methods for fostering experiential learning, interdisciplinary topics, renewing of course contents, etc.).

In the following section, the research context is described in order to introduce the research question in the next section. The other sections show the results of this first experience and the consequent discussion with a view to a possible implementation of the tool.

BACKGROUND/CONTEXT

The term 'inclusion', in educational, refers to the idea that everyone should be able to use the same facilities, take part in the same activities, and enjoy the same experiences, including people who have a disability or other disadvantage. More in detail, for the US National Centre on Educational Restructuring and Inclusion, it is the provision of services to students with disabilities, including those with severe impairments, in the neighbourhood school in age-appropriate general education classes, with the necessary support services and supplementary aids (for the child and the teacher) both to ensure the child's academic, behavioural and social success and to prepare the child to participate as a full and contributing member of society (Frederickson & Cline, 2006; Jamison, et al., 2014).

In literature, recent experimentations of the transformation from the traditional teaching to a student-centred one in higher education are reported (Catalano & Catalano, 2013; Ross & Judson, 2018; Leshner, 2018). In particular, the group learning is been implemented in technical courses, such as the electrical field, with a significative result in terms of the generation of long-term knowledge (Marth & Bogner, 2017; Chance, et al., 2013).

In the Italian panorama, there are numerous and differentiated attempts of inclusion and support in favor of the students with greater difficulty. However, it is not usual to stimulate the personal skills of each student in a differentiated and targeted manner by creating varied parallel paths with different levels of study on the same topic. Historically, the course of study is structured with a unique curriculum depending on the chosen major of interest.

Recently, in Engineering Education (EE), a huge effort is been invested on the protégé students' inclusion. Therefore, due to the limited resources, the attention on the deserving students is been mostly neglected. This choice, however, had negatively affected the overall quality because the Talented Students (TS) lose their stimulus. The direct negative feedback was a prolongation of the graduation time. Thanks to an experimentation called "Research among Quality - Young Talent track", started in a.y. 2014/15 at Politecnico of Torino (PoliTo), the empirical definition of a reverse inclusive process is been attempted and its positive overall impacts have been recorded (Ballatore, et al., s.d.).

The PoliTo, with 4500 freshmen every year, is organized with a first-year path equal for all the different majors. The curriculum differentiation starts in the second year. During the first year, students study Mathematical Analysis I, Chemistry, Physics I, Linear Algebra and Geometry, and Computer Science and are divided into 20 parallel classes (two of them taught in English).

AIMS, RESEARCH QUESTIONS, AND METHODOLOGY

The aim of this research is to discover which are the advantages of a reverse inclusive process inside a Technical University. To do this, the following questions were considered as guidelines of the educational research activities performed:

- Which is the empirical definition of reverse inclusion in EE?
- Which are the overall impacts and benefits of this process?

In order to address this questions, the TS's program was used as a reference. In fact, this partially funded project has given the possibility to enrich the Bachelor's degree curricula of the top 4% of freshmen with Hybrid Activities (HA) (Jamison, et al., 2014) and courses reinforcements. Considering the overall 4500 engineering freshmen, the students selected for this project are around 200. The selection is firstly based on the enrollment test; then, the students' performances are checked at the end of each semester in term of number of ECTS and average exams score. As a consequence, an incoming and outcoming flux of participants to the project is in place until the first semester of the second year.

By looking at the gender (male to female) ratio, although at the PoliTo it is about 3:1, inside the project it is higher, since the male students are around 85% of the participants. The reason why the females are present in a more limited amount on the top fraction of students is currently under investigation.

Having in mind the pedagogical benefits of inhomogeneous class and our research objectives, the TS are following the standard lessons with all the other students. At PoliTo thanks to the first common year for all the majors, students are grouped in classes of about 250 students based on an alphabetic order. The project structure and methodology are been built with a high degree of inclusion between the different groups of students, in particular either between TS and all the other students, that inside the program itself.

The TS's supplementary activities can be distinguished between those devoted to the implementation of the standard curricula and the hybrid activities. The first ones includes the offer, to small groups of about 60 students, of additional scientific and technical contents: two curricular courses of Mathematical Analysis I, and Chemistry during the first semester, and the complete in-depth teaching of Mathematical Analysis II, at the first

semester of the second year, and of Physics II, during the first semester of the second year, that are taught to the TS homogeneous class. The aim of this competence reinforcement is to provide a more organic, practical approach to the laboratory sections and an 'in-depth' view of the topics covered, above all by stimulating a more autonomous study and enhancing willingness to an interdisciplinary approach. The hybrid activities instead have the aim of training TS in non-technical areas, such as soft-skills, critical thinking, humanities, and creativity. These activities have been gradually increased during the academic years. The students were involved in few daily or weekend sessions during the first year. The activities lasted several weeks during the second year, and finally they covered a full semester in the third one.

This study is based on one complete cohort of students, the first one included in the project, and partially the second one, since for this cohort of students the graduation period is not still ended. The authors ensure that all relevancies are confirmed by the following cohort and then this simplification is reasonable.

FINDINGS

The presence of motivated and reactive TS inside the regular classes naturally ensures a strong peer to peer learning. Indirectly, the protégé students receive a nudge that helps them keep up the lessons time. Spontaneously TS and protégé study together in groups. This allows students to share views, review the notes and solve problems together. It also makes the workload lighter and helps them stay on track with their study commitments.

This is been registered with a reduction in the graduation time with a higher score degree average, despite the already mentioned increase of freshmen (Table 1). This reduction is clearly stated by the comparison with the values presented by the cohort of students matriculated before the beginning of the project (a.y. 2013/14). A net positive trend is also observable comparing the first and second cohorts involved in the project.

An observation of the phenomenon is been performed in order to better understand what was occurring. It is firstly necessary to remember that no changes were been made on the traditional support for protégé students, namely (i) the available online materials and courses on background knowledge in order to help students recover lacks before the first year beginning, (ii) the video recorded lessons and tutoring during the first year and the first semester of the second year, and (iii) the supplementary course for those who failed exams during the first semester of the first year.

Table 1 - Number of students graduated in 3 years with the related average degree score, the percentage of drop-out during the first year and the % of students that fail the first-year minimum requirements (*not including the whole graduation period). The green backdrop characterises the two cohorts considered in this study.)

a.y.	Matriculated	Graduated in 3 years	Average degree score (3 years)	Drop out during the first year	Minimum requirements not satisfied during the first year
2013/14	4168	893	100,9/110	13,9%	23,8%
2014/15	4432	980	101,2/110	11,2%	21,0%
2015/16	4518	1136*	/	10,9%	16,3%

Having a group of stimulated students across all different engineering courses gives also the possibility of a direct feedback on the curricula. Then, in case a review of contents or of course organization is needed the TS can be actively involved in testing the new design. This can be done because the size of this group is perfectly reflecting a standard PoliTo class (around 200 students). Thanks to their feedback and reactions, collected in a yearly survey, the new or renewed course could then be proposed, after optimisation, to all the students starting from the following academic year.

Some concrete examples of this “managerial” application are first-year workload, the content review of the Geometry course, and the benefits expansion.

CRITICAL DISCUSSION

Speaking about ‘reverse inclusion’ can seem a paradox, however, the empirical definition can be stated as the process that, by stimulating the TS, indirectly includes and supports the protégé students. This has a double advantage because both protégé and talented students receive special training that ensures increasing overall quality.

As already said, the project for TS foresees the common attendance with all the other students of most of the subjects. This creates a proactive environment during standard lessons: deserved students break the ice, asking questions, exchanging views and generally this taking part involves the students with more difficulties that are free to be proactive in

turn. In this way the entire class of 250/300 students is participating and expressing doubts, recognizing that being in class can also be an active exercise and a chance to study.

This peer-to-peer interaction, in particular, affects the quality of each student's study that is summarized by the reduction of drop-out, of fail in the achievement of the first-year minimum requirements (28 ETCS) and of the graduation time.

In Table 1 the growth of the number of matriculated students is clearly mapped. Usually, this increase has a negative impact on the overall quality of the enrolled students. This is due to the fact that the additional students generally are coming from the protégé area. Thanks to the reverse process the drop-out during the first-year decreases of 3%. Reaching almost a 10% of deflection is a very good achievement if the overall number of students is considered. Similarly, the number of students failing the first-year minimum requirements of 28 ECTS over the 60 achievable is visibly reduced. This means that more students are able to access to the second-year courses in time, and consequently to have the possibility to graduate in time. In fact, this effect is reflected also on the number of students which graduated in time (3 years) and on the increase of the average score, too. Therefore, these results clearly state that this program helped and stimulated the overall students community and not only the TS involved.

Considering now the managerial advantage of having a small group of talented students, some concrete examples of how reverse inclusion have positively affected the curricula review and the students' benefit are now critically discussed.

a. First-year workload

Considering the yearly survey results, the TS reported that the work-load was not well balanced between the two semesters of the first year. For this reason, considering the background requirement, the Computer Science course was the best candidate to be anticipated from the second to the first semester. Starting from a.y. 2015/16 this course anticipation is been implemented for all students.

During the survey of a.y. 2016/17 the deserved students highlight a better workload balance between the two semesters without reporting any missing course requirements.

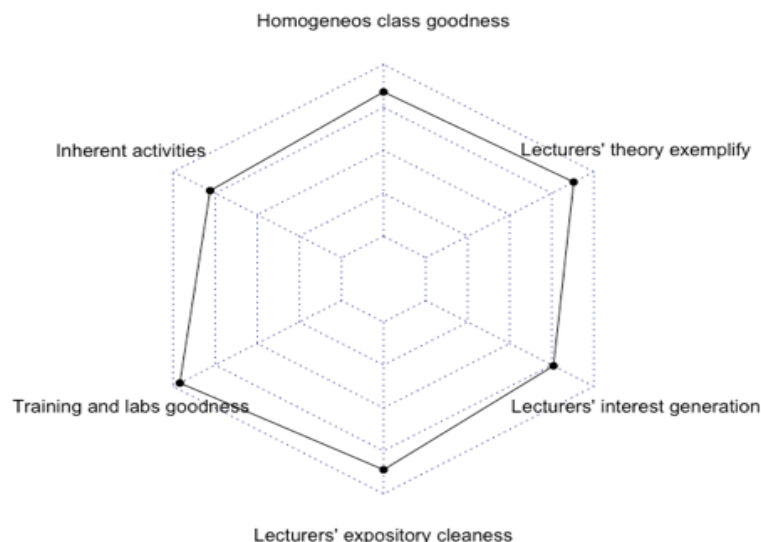
b. Geometry course content review

Similarly, the standard Geometry class needed a review in term of contents with a reinforcement of the Linear Algebra part and the introduction of MatLab software. A new course of Linear Algebra and Geometry has been planned. The new syllabus has two main goals. The former is to introduce the main topics of these subjects, training the student to follow logical deductive arguments and to use the proper formal language. The latter is to give students the main concepts of some basic numerical methods of linear algebra and of the implementation in MatLab.

As the TS can perfectly simulate the numerosity of a standard class and can help lecturers judge the goodness of the new syllabus, the reviewed course has been proposed inside the program.

The students have been given a very positive feedback about this new course (Figure 1). Thanks to this trial, the contents among Mathematical Analysis I and II, Physics and Geometry courses have been synchronized. Starting from a.y. 2016/17, the new 'Linear Algebra and Geometry' course has been suggested to all students on the traditional path instead of the previous Geometry one.

Figure 1 - Radar plot with the results of the survey on the Linear Algebra and Geometry course



c. Benefits expansion

As a part of the program, TS receive some benefits such as a card for free access to many regional museums and public transportation subscription. Looking at the survey data collection, the services were frequently used with a positive impact in term of interest. For

this reason, starting from a.y. 2017/18, these tools have been offered to all the students enrolled just with few limitations related to family income and academic results.

CONCLUSIONS AND RECOMMENDATIONS

By considering the results achieved, the empirical definition of a reverse inclusive process can be stated as all those activities that, thanks to the mixed class formation, indirectly include the protégé students by stimulating and motivating the talented ones.

The peer learning, for example, is automatically activated and reinforced increasing the overall knowledge level and reducing the career duration. In addition, this awareness on the presence of stimulated TS allowed to test improvements of the course contents or their modifications on such a small and well-responding TS class. Such monitored and balanced test of a curriculum review is a great advantage to the entire students' community.

In order to guarantee the spontaneous activation of the reverse inclusive process, the TS program must be designed to be strongly inclusive, that is aimed to facilitate the interactions both inside the TS group that between TS and standard classmates.

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Paper 5: A novel methodology for feedback for large classes in partnership with the students

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KEYWORDS: Assessment and feedback, student partnership, pseudo- personalized, large class size

ABSTRACT

Generally, providing individual feedback, in the case of large-sized classes, is near impossible or would require disproportionate effort to do so. Generic feedback, instead, has a little value in enhancing students' learning and their satisfaction. Consequently, the authors of this paper have proposed a novel methodology to overcome the two extremes of such feedback procedures i.e., individual feedback and generic feedback. In this paper, the authors propose a pseudo-personalized feedback mechanism in which the feedback is clustered into several categories according to the correlation in the student response to the assessment. The feedback process is completed in partnership with the students.

INTRODUCTION

Assessment and feedback (A&F) are central to any educational process, in particular to higher education. In view of National Student Survey (NSS), an exceptional score in this category can help in improving the overall university ranking. Every academic institute attempts to achieve better scores in the A&F section of NSS and prepares some action plans accordingly to improve the scores. Through UK Professional Standard Framework (UKPSF, 2019), Higher Education Academy (HEA) also considers the importance of A&F, for instance, A&F is considered a key area of activity (UKPSF – A3), which highlights, “assess and give feedback to learners”.

However, it is always difficult for the instructors to provide individual feedback, especially for large classes. As a result, student expectations are not always met in regards to A&F. An efficient A&F process can lead to several positive outcomes including greater student engagement and improved learning abilities. However, there should be some simple and effective A&F mechanisms which not only achieve the required objectives but also make the process smooth for both academics and students.

LITERATURE REVIEW / RATIONALE

A student has to go through various forms of assessments during their course of study. These assessments could be in the form of exams, laboratory exercises, presentations, essay writing etc. (Race, 2007 and Race, 2009). While each sort of assessment has its own pros and cons, it becomes extremely important to provide targeted and tailored feedback to the students on their assessments in order to improve their learning. However, it is difficult to prepare and provide effective feedback particularly to a large class size. Not only it is important for the instructors to select the correct form of assessment but also correct means of providing feedback are necessary to enhance student learning. Further, the A&F process should be able to stimulate and inspire students to learn (Hounsell, 2008).

Irrespective of the nature of assessment, summative or formative, providing individual feedback is a time-consuming process which may involve inconsistencies, illegible handwriting, and vague remarks (Chanock, 2000). The automated feedback (Biggam, 2010) is another form of providing seemingly personalized feedback but they also need editing in some cases and may appear relatively generic to a wider community of students and thus not fulfilling the basic requirements of the A&F process.

On the other hand, involving students in the A&F process results in greater student engagement and the development of the feelings of being part of the learning process at the students' end. It shifts the balance of power by giving some control to the students over their learning (Vickerman, 2009). There are several advantages of involving students in the A&F process which include better student understanding of the academic standards of the module, assessment criteria and how they are applied to their work (Bloxham and Boyd, 2007). Also, it improves their ability to judge and provide constructive feedback to the peers.

The rationale behind the study is to find a more effective feedback procedure instead of the existing generic and individual feedback procedures with the student partnership. Individual

feedback demands more resources and efforts while generic feedback is less consuming but less effective towards student learning improvement.

AIM AND OBJECTIVES / RESEARCH QUESTION(S)

In light of the above discussion, we propose a novel feedback framework with the following aims:

1. To engage the ex-students in the feedback process
2. To divide the assessments into appropriate clusters according to their feedback correlations
3. To provide detailed feedback through ex-students for each feedback cluster
4. To provide top-level feedback through instructor in the form of videos

METHODOLOGICAL APPROACH

The study was implemented for year 1 students in the course of Microelectronics Systems in EEE program in their Fall semester. There were approximately 202 students who participated in the process and the feedback was provided before the midterm exam to observe the effectiveness of the feedback in their performance in the midterm exams. 3 senior students who took the same course last year were selected for partnership. The whole process was completed in partnership of these 3 students who shared the responsibilities of implementing all the project steps.

After the completion of the study, the students completed a reflective feedback questionnaire about all the components of the project including feedback quality, timeliness of the feedback etc. on a 5-point Likert scale. The use of Likert scale helped in quantifying the results. There were some open ended questions to provide the commentary about overall quality of the feedback process. It was made an intentional effort to ask the students to complete the questionnaires in their lab hours to increase the student participation. While the student participation was very high, it was observed that there were some students who would not complete the questionnaire with much interest and would provide random scores. An introductory session before handing over the questionnaire could help to increase student interest in providing feedback. Further, some focus group interviews were also conducted with the student partners and their feedback was also recorded.

THE ENGINEERING EDUCATION PROBLEM AND INTERVENTION

Our objective was to search a trade-off solution which could work efficiently and effectively for large size classes while providing feedback. We proposed a new framework with feedback provided in two steps to solve the problem. Ex-students, who were considered to be the top students, helped in preparing the clusters of the answer sheets. The answer sheets requiring similar feedback were grouped together in a cluster and thus five different feedback clusters were prepared. The students also helped in preparing the pointers for each feedback cluster to help the instructor prepare feedback videos accordingly. The details of the two feedback steps are given below:

Feedback Step I: The instructor studied the feedback pointers prepared by the ex-students. Then the instructor prepared a set of feedback videos based on the given information. There was one video to address each feedback category. The instructor discussed the criteria for the students to fall into that particular category and the most common strengths of the students observed during the assessment process. It also highlighted the most common weaknesses, the reasons for those and subsequently presented tips to avoid such in the future.

Feedback Step II: In the second feedback stage, the ex-students provided detailed feedback on the work of all the students who participated in the assessment phase. This detailed feedback also includes the detailed solutions of the assessments.

It is worth mentioning here that the study was conducted for formative assessment and feedback and the purpose was to provide students the guidance and support to prepare better for the summative assessments which are considered towards their grades.

KEY FINDINGS

Some of the key findings include the response about the timely availability of feedback, the usefulness of the feedback, comparison to the generic feedback (GF) and individual feedback (IF). As shown in Fig. 1, around 83% of the students agreed/strongly agreed about the in time availability of the feedback. It is worth mentioning that the feedback process was completed within 3 weeks. The feedback was considered useful by more than 88% of the participating students— whereas 85% of the students agreed/strongly agreed to the feedback method being more efficient as compared to generic feedback. Approximately 81% of students agreed/strongly agreed to the method being a good alternative to individual feedback. There were around 79% of the participants who considered that the video feedback (VF) was a value addition (VA) to the detailed feedback that they had through the ex-students. Moreover, 86% of the students agreed/strongly agreed that the

feedback was clear and understandable. Approximately 80% of the students considered that the feedback was relevant to their needs and requirements.

The ex-students who were involved in the feedback process considered the experience as enjoyable, challenging and worth investing time to gain the insights about the feedback process. On average, the students performed better than the previous year students in the midterm exam, however, the improved feedback process might not be the only reason for that improvement.

Fig. 1: Feedback questionnaire results (red – strongly agree, yellow – agree, blue – neutral, green – disagree, orange – strongly disagree, dark blue – no response)



DISCUSSION

The assessment and subsequently feedback were conducted before the summative assessment where the delivery of the feedback concluded days before the actual assessment. The practice can be considered successful from the perspective of the instructor as well as the students. Being the instructors, we realised some of the aspects of the feedback process that might still be made more efficient in terms of implementation e.g., the clustering of the assessment could be made efficient in terms of more distinctive clarity among different clustering categories. The student had a great opportunity to test their knowledge level and have feedback on their strong and weak learning aspects. Moreover, they were also provided experienced feedback on improving their exam performance by the use of some tips and tricks. Although the whole assessment and feedback process took a lot of time for the students to prepare and perform but it was worthy in terms of better grade reflection in their summative assessments.

The study can be adopted for any engineering education program and in particular, for programs having a large number of students. Involving ex-students in the feedback process can not only help in their own learning but also improve the feedback process in regards to

time and efficiency. Using time efficient and outcome oriented feedback methodologies like the one presented in this paper can be adopted by other engineering instructors and benefit a large community. However, a detailed research analysis of the study would be required in order to contemplate whether the proposed framework can replace the individual feedback. In our view, although not as useful for small classes, but the practice can benefit the students as well as instructors for large size classes where the individual feedback is almost impossible to provide in most of the scenarios.

CONCLUSIONS & RECOMMENDATIONS

The paper proposed a novel methodology to improve the feedback for large-sized classes. Some ex-students were involved to prepare assessment clusters based on the correlation among student responses. The clustered feedback process was found less time consuming and a good alternative to individual feedback to enhance students' learning and satisfaction. We plan and recommend to trial the methodology for various courses with varying class sizes to critically evaluate the effectiveness.

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Paper 6: Exploring Applications of VR in Civil Engineering Education

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KEY WORDS: VR, engineering, construction, conceptual design, spatial awareness

ABSTRACT

A key component of the Swansea University Civil Engineering training is based around the exploration and development of imaginative, viable Civil Engineering conceptual solutions to problems. In industry, conventional methods for conceptual design communication, such as sketching, physical modelling or 2D CAD drawings are now generally superseded by 3D and 4D (space + time) computer visualisation methods, which go hand-in-hand with the growing UK industry adoption of Building Information Modelling (BIM). In this paper the authors present two studies in which Virtual Reality technology was deployed, to assess whether the use of such methods could enhance the development of concept design skills and spatial awareness in the context of spatially complex, real-world based design problems.

BACKGROUND

There is a growing body of literature that supports the need to evolve engineering education in response to a reported lack of relevant skills amongst engineering graduates. The IET Skills and Demand in Industry Report states that only 62% of engineering employers believe that graduates have the right skills for a modern workplace (Institution of Engineering and Technology, 2017).

A key component of the Swansea University Year 1 Civil Engineering module “Conceptual Design” is the training of students in the development and exploration of imaginative, viable Civil Engineering conceptual solutions to problems (concept generation being “an approximate description of the technology, working principles, and form of the product...usually expressed as a sketch or as a rough three-dimensional model...”) (Eppinger & Ulrich, 2011). Conventional methods for conceptual design communication, such as sketching, physical modelling or 2D drawings are now being significantly enhanced or even entirely replaced by 3D and 4D (space + time) computer aided design (CAD) methods. Research by Ibrahim et al (Ibrahim & Rahimian, 2010) suggests that whilst for early-stage

architectural creative design conventional CAD tools can hinder novice designers' creativity, such tools are indeed advantageous for detailed engineering design articulation. Chang et al (Chang, Chien, H-C, Chen, & Hsieh, 2016) suggest that not only can the use of 3D CAD for design impact positively on students' creative performance, it can potentially also overcome a shortfall in representational ability, such as poor hand sketching skills.

In the UK Civil Engineering and construction sector, Building Information Modelling (BIM) – here referring to “a digital representation of physical and functional characteristics of a facility.... a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition” (National Institute of Building Sciences, 2018) - is now mandated for certain types of Government-funded projects. This is due to the multitude of advantages which have been identified as being made possible through the early adoption of BIM, including at the design team level an improved collaboration between designers and supply chain partners, better planning and design between teams, improved clash detection and therefore reduced need for late stage redesign, as well as resource efficiencies associated with working within a single computer design platform. Customer benefits include rapid early stage prototyping of multiple concepts, the potential for reduced energy use and carbon footprint through life-cycle modelling, as well as comprehensive asset data at handover in the form of the BIM model.

Companies within the UK engineering, construction and related sectors are continuing to make very significant investments in technology and training in order to become BIM-expert providers. In 2017, a survey of 1,000 UK construction professionals revealed that BIM adoption has increased from 13% in 2010 to 62% in 2017 (NBS, 2017). Therefore, it must be recognized by those teaching Civil Engineering in UK Higher Education Institutions that knowledge of BIM and the development of skills in the related technologies is now a must-have for graduates. This is part of a consistent trend across the wider engineering sector, with 30% of companies have firm plans to increase their current use of digital technologies (IET, 2017).

Virtual Reality in industry is also becoming more common. Research by Woksepp et al (Woksepp & Olofsson, 2008) confirmed that even more than a decade ago, industry professionals such as designers and planners, as well as clients, accepted and were positive about using VR models in the design and planning stages of construction. Identified barriers to adoption principally arose from technological limitations of the time. Approximately 10% of engineering companies are now routinely using Virtual Reality in some capacity (IET, 2017).

Autodesk Revit is by far the dominant software for BIM, used by 41% of industry professionals (NBS, 2017). In the academic year 2016-17, the teaching of 3D BIM modelling was introduced into the Year 1 Civil Engineering module EG-122 Conceptual Design, utilizing Autodesk Revit software and its training materials. The following academic year this

teaching also trialled the addition of Virtual Reality interactivity, and it is this trial which forms the basis of VR Teaching Study 1 of this paper.

LITERATURE REVIEW

Spatial intelligence is a skill central to Civil Engineering. During construction, site engineers need to plan logistics in advance to enable the safe and efficient placing of plant and materials during construction. Structural designers need to be able to visualise how changes in a design will affect the final structure. Much of building and infrastructure Civil Engineering activity is the management of the translation of conceptual or paper/screen-based plans to reality, for which spatial skills are vital.

In this paper, the definition of spatial intelligence as defined by Gardner (1983) has been adopted. Gardner defined a total of eight difference intelligences, the others being linguistic, logical-mathematical, musical, bodily-kinesthetic, naturalistic, interpersonal and intrapersonal. Spatial intelligence is defined as “an ability to recognize and manipulate large-scale and fine-grained spatial images.”. It is now a commonly accepted view that intelligence is influenced by environmental and not solely genetic factors. Studies appear to support this, including that of Martin-Guiterrez, Jorge, Navarro, R.E. and Gonzalez (2011), who tested the spatial ability of Engineering students before and after using an augmented reality learning system. The study showed that compared to the control group, the engineering students engaging in the AR training improved their spatial ability test scores.

Faas et al (Faas, Bao, Frey, & Yang, 2014) conducted an experiment where the users’ sense of “presence” was utilized as a metric for measuring the designer’s level of engagement and involvement in a physical (non-VR) design task. The study found that the degree of “presence” experienced by the designer in the activity is a performance indicator directly proportional to the resulting project quality - that is, that whenever a designer feels “present” or highly engaged within an activity, better design solutions will be generated. Paes et al (Paes & Irizarry, 2016) suggest that “where a given virtual reality system offers a higher level of presence, it becomes capable of improving designers’ performance in design review and critical analysis tasks, through improving spatial comprehension on the virtual model”.

Further research by Paes et al (Paes, Arantes, & Irizarry, 2017), investigated how users’ spatial awareness changed when immersed in a VR building design compared to when using a non-immersive building design on conventional PC workstations. They conclude that “the immersive environment may benefit current design practices by improving professionals’ understanding of the spatial arrangement of the virtual model”.

It is worth noting that Bouchlaghem et al (Bouchlaghem, Shang, Whyte, & Ganah, 2005) advocate that “the process of design and visualization should be iterative, with changes

made as a result of insights gained through visualization propagated into the next version of the design”, therefore VR should not be considered as a tool to simply view an end-product, but an integral aid within the whole conceptual design development phase.

AIM AND OBJECTIVES

VR Teaching Study 1:

The aim of this study is to investigate whether the enhancement of BIM modelling with VR-interaction can improve students’ understanding of and interaction with their 3D conceptual design.

The specific objectives of this study are to investigate:

- Does the introduction of immersive modelling enable students to better understand the spatial arrangement of their model?
- Does immersive modelling enable students to interact more easily with their models during development, compared to traditional non-VR CAD methods?

VR Teaching Study 2:

The aim of the study is to gain an understanding of whether students are appropriately conceptualising the scale of their designs.

The specific objectives of this study are to determine:

- How spatial intelligence varies between students (are students good predictors of the scale of their designs)
- Does VR have potential to be a meaningful addition to problem-based learning in construction management.

METHODOLOGICAL APPROACH

VR Teaching Study 1:

Participants in this voluntary study were from a cohort of 152 first year undergraduate Civil Engineering students studying at a UK University. The computer laboratory exercise in 3D building development using AutoDesk Revit was uniform across the cohort and associated with a 20% coursework component, which had been delivered in a near-identical manner the preceding year with good outcomes. The addition of VR-interactivity in the model development was voluntary and no additional marks were associated with participation in the study. The three computer laboratory sessions associated with the course, that is lab 1- 3D modelling skills classes, lab 2 - model development and lab 3 - VR and model

development, were delivered in a staggered fashion to groups of approximately 50 students per laboratory session, evenly spaced over the 10-week teaching period.

After receiving College Research Ethics Committee approval, participants were recruited in a lecture prior to the delivery of the VR computer laboratory session or at the laboratory itself. Students who provided their consent to participate then took part in recorded focus groups or individual interviews that were conducted by one of the graduate teaching assistants who supported the workshop.

Information about the VR study was disseminated to students during lectures in advance of the laboratory classes and made available in written form via the University electronic learning environment, Blackboard. Students were invited to participate individually in the VR study in two ways – through the use of smart-phone based static VR (limited interactive VR functionality) using Google Cardboard headsets or through fully-interactive mobile VR utilizing HTC Vive VR headset and wands, with capacity for an enhanced VR experience through the manipulation of daylight/night-time settings. In both cases the link from Autodesk Revit to VR visualization was enabled through the “Kubity VR” application for smartphone and PC.

Those participants using Google Cardboard headsets could do so in a self-guided manner, whilst seated at their workstation, with minimal support from the lecturer and graduate teaching assistants. Those participants utilizing the HTC Vive equipment did so in a cordoned-off space within the laboratory, supported by two graduate teaching with extensive training in delivering VR teaching activities. Each of the VR computer laboratory sessions was approximately 3 hours in duration.

The focus groups and post-activity interviews included questions that addressed the following themes: students’ experiences of the simulations; benefits and disadvantages for learning; challenges of its use; aspects liked and disliked, and, any effects on personal perceptions of spatial awareness and scale. Participants were also encouraged to add any comments not addressed by these topics and the exact order and phrasing of questions was modified in response to group and interview discussions. Written feedback relating to the VR activity was also extracted from anonymous end-of-module online student surveys, which are carried out for all taught modules within the University.

VR Teaching Study 2:

The module chosen was a 10 credit Level 6 (final year of BEng degree) course on Construction Management at Swansea University, with 166 students enrolled. The module adopts a predominantly problem-based learning style to cover module content on site logistics, activity scheduling, costing and risk management. Problem-based learning (Barrett & Moore, 2011) places complex, real-life problems at the centre of the learning process and is anchored in principles of constructive alignment (Biggs, 2003), where the learning process is designed to allow students to learn by construct meaning through the activities they participate in.

There are minimal lectures, most of the learning takes place in workshop sessions with the students with most of the learning activities derived from real-life problems set and assessed by practicing contractors who are lecturers on the course.

In this case study, the students were learning about determining construction method – the process of investigating and comparing options for construction activities on the basis of time and cost.

Dawnus, a locally-based national contractor, provided the case study – installation of a 20 m x 2 m diameter stormwater attenuation tank, with the invert installed 6 m below ground level. Baseline information including site drawings, ground and groundwater conditions, and the cost of available plant and manpower. The students were required to investigate options for installation of the tank, which could include inclined or stepped excavation edges or installation of sheet pile walls to form a cofferdam.

The students worked in groups of five or six on the problem in 2 x 2 hour sessions, held in consecutive weeks. During the first week, they carried out an exercise to compare the cost and time of different excavation methods. In the second week, they produced a detailed cost and time outline of their preferred method.

After the end of the second session and once the assignment had been handed in, the students were invited to view VR tours of the site both pre- and post-excavation. The VR tour had been recorded around two months previously and was a static view, navigable tour recorded with a Samsung Galaxy 360 camera and accessed via a smartphone and a Google Cardboard headset. Students could navigate between different photospheres, and place themselves at approximately 20 different locations in and around the site in its pre-excavation and post-excavation states.

This 360 camera/ Google Cardboard combination is a comparatively cheap and accessible method of incorporating VR into teaching. The cost of a 360 camera is typically £200-£300 (€220-€330). A Google Cardboard headset costs £5-£10 (€5-€11), and the system will work with any recent smartphone.

A total of 18 students opted to view the VR excavation, and five opted to be interviewed in more detail afterwards about how their VR experience of being placed inside and above the VR excavation compared to their conceptualisation of their designed excavation. The interviews lasted between 2:30 and 6:00 minutes. Of the five students who were interviewed, two were female, three were male. Three of the students were international and two were home/EU.

This study was approved by the College Research Ethics Committee and informed consent was obtained from all participants. To mitigate potential bias in the responses, the interviews were conducted by an academic who was not involved in teaching or assessing

this cohort of students. The students were informed that the module coordinator would not have access to the data until after the end of all module assessment.

KEY FINDINGS

VR Teaching Study 1:

Student engagement with the self-guided VR experience (using Google Cardboard headsets with smartphones) was good, with up to one quarter of those in attendance at the lab sessions engaging in that aspect of the activity at some point within the lab session. Individual engagement in the VR activity typically ranged from 5-30 minutes. The principal reason cited for non-engagement was the preference to utilize that lab time to continue working on the core component of the lab activity (the assessed 3D Revit model development). The number of students who then went on to utilize the HTC Vive VR equipment was more limited (around 10 students in total), but the level of engagement of those individuals was notably high. Feedback from the voluntary focus groups and post-activity interviews, transcribed from the recorded audio data, gave qualitative data over a range of topics.

In terms of the benefits to learning:

Feedback 1: *"It was pretty interesting being able to visualise in 3D using Kubity – obviously it's quite hard to transfer a 2D drawing in your mind into something that's 3D and tangible – it was quite beneficial to be able to put on the equipment and actually walk around the model that you had just created".*

Feedback 2: *"Using VR I found doors and walls that were the wrong height - I hadn't been able to see it in 2D".*

Feedback 3: *"Being able to walk around the model it was really quick and easy to find faults with my model. It helped me with the coursework because it helped me spot mistakes that I otherwise wouldn't have found".*

Feedback 4: *"You're building the building as you walk around it!"*

Feedback 5: *"As the engineer I could visualise the building more easily"*

Feedback 6: *"It would be beneficial to use this technology in any future design assignments".*

In terms of the usability of the VR, the enjoyability of the session:

Feedback 7: *"The VR session was fantastic - I had never experienced VR before, and aside from being a fun experience navigating around a building I had completely drawn myself, it actually helped me with the coursework".*

Feedback 8: *“Google Cardboard has been useful for learning in the lab in large groups. It’s a good basic VR that everyone can use in class at the same time”.*

In terms of provoking deeper thoughts around the building conceptual design:

Feedback 9: *It would be interesting to visualise how groups of people move around the building ... to know where to widen doorways, move a column”.*

VR Teaching Study 2:

The observations of the students who were using the VR system were not formally recorded, however, it was noted that all of the 18 students who tried the VR tour appeared to be surprised or enjoyed the experience.

The interviews asked the students questions about the task and the VR experience, seeking to understand if it has any potential to add value to the project-based learning exercise.

In response to the question **“Did you like the experience?”**, all five respondents responded positively, e.g. *“Yeah, it was really good fun”*; *“Very interesting”*; and; *“It was very useful for me to discover the site and help me to see the site and see more things and more details”*. When given the opportunity to explain why they liked it, they tended to mention improved realism and perspective: *“It was just a bit different and just sort of put you in a real life situation more like it would actually be on site”*.

In response to the question **“How does the excavation align with your prediction?”**, intended to indirectly probe whether scale would be mentioned, responses varied, e.g.: *“Sort of as I expected, I suppose we have some experience with what’s going on next door (referring to new building construction on campus), but I suppose this would provide the opportunity for people who can’t visit the site to see the same things that I’ve seen through the app and through actually going on site visits”*; and; *“Well firstly our method is slightly different to our excavation, secondly, I, like once I visualise it now, I realise it’s much bigger than what I anticipated it to be. When you draw on a map, it doesn’t, you don’t feel how deep it is, you don’t get an actual realistic feel. But when you look at it now, I oh... I actually thought you know, it’s bigger than I thought it would be.”*

In response to the question **“How does the VR experience affect your understanding of the task?”**, all five responses were positive, e.g.: *“I think it clarifies the task a lot more, so, although I understood what to do, it sort of puts it in more of a real life situation, so that you can actually, you don’t have to imagine what’s it’s going to be like, you can actually see what it’s going to be like”*; and; *“I can know the size, understand the size connection clearly without going down to the site, so I can just sit in the office and know everything”*.

DISCUSSION

VR Teaching Study 1:

The aim of this study was to examine whether VR can improve students' understanding of and interaction with 3D conceptual design within the context of the development of a spatially complex 3D building information model. The findings of this study demonstrate that the enhancement of 3D building modelling with VR during the model development phase does enhance students' ability to engage in the modelling process and ultimately does aid students in improving the quality and correctness of their 3D Revit BIM model.

Qualitative data identified that the addition of virtual reality consistently helped students to identify errors in their models which were difficult to detect in the non-VR setting (viewing the 3D model on a PC within the Revit software) and that the ability to "walk through" the building enabled a greater sense of the spatial arrangement of the rooms, circulation spaces, stairways etc to be developed. It was noted during informal conversations at the laboratory sessions that students who had experienced the VR activity were more likely to have a deep understanding of the building arrangement and show evidence of high-level conceptual design thinking around topics such as user-interaction with spaces, material finishes, the impact of changing lighting conditions eg. daylight vs. night-time.

VR Teaching Study 2:

The first objective of research was to determine whether students understand the scale of their designs. In this, the data is mixed. Only one student out of the five specifically mentioned the scale of the excavation was larger than anticipated. It is worth noting that the wording of the questions did not mention scale. This was deliberate and intended to not bias the students towards mentioning scale unless this was a feature that particularly stood out for them. However, the students appear to have interpreted the question 'How does the excavation align with your predictions', as an invitation to comment on the differences between their design of the excavation and the real one, rather than the scale. Possibly as the interviewers were not associated with the task design (this was required for ethical approval) they did not know to probe further or adapt the questioning to prompt the students to reflections on their conceptualisation of the excavation prior to, and after viewing the VR tours. Future research will include a specific question on scale to elucidate whether the students are or are not accurately conceptualising the scale of their designs.

The second objective was to investigate whether VR has potential to be a meaningful addition to problem-based learning in construction management. The data reveals that amongst this small sample, there is overwhelming positive regard for this reasonably basic and relatively cheap VR solution, and that it appears to offer benefit to the students in helping them understand the task better. According to the students, themes of realism, improved perspective, and clarity emerged as reasons to use VR in classroom activities.

The classroom exercise had been designed to be a good quality PBL exercise, with an authentic, open-ended exercise set, requiring peer cooperation and resource investigation. However, a construction site is a complex environment, and the limitations of transferring a context-rich activity to a classroom setting is the inevitable truncation of information provided. The VR experience does appear to provide an enhanced level of understanding of a site-based problem based learning task.

CONCLUSIONS & RECOMMENDATIONS

These two studies were carried out in response to evidence that digital technologies, including BIM and virtual reality, are increasingly gaining traction in industry (NBS, 2017; IET, 2017). As a vocational discipline deeply rooted in spatiality, Civil engineers are required both to visualise (e.g. in design) and understand orientation (e.g. in site logistics). It is therefore arguably of importance for Civil Engineering education to make specific efforts to develop the spatial intelligence of graduates. There has historically been an understandable difficulty in achieving this, arising from the large scale nature of Civil Engineering structures, making it impractical and usually impossible for students to complete their classroom designs.

The recent developments in accessible VR technology, specifically the smartphone compatible devices (e.g. Google Cardboard) used in these studies, offer new opportunities for Civil Engineering educators to connect theory with practice. More advanced systems such as the HTC Vive used in Study 1 allow a greater degree of interaction, but are significantly more expensive and difficult to use with large student groups. In Study 1, it was shown that the immersive environment provided by VR enabled students to better identify errors, and to understand user-interaction with designed spaces. In Study 2, there is evidence that some students will be surprised when immersed in their design, indicating a poor level of spatial prediction based on the paper-based exercise. The VR experience in the second case study added a sense of clarity and realism that the students appreciated.

These findings add to existing evidence that the use of immersive environments can be a highly accessible method for engaging with engineering and construction and as such could be an important tool in the delivery of teaching of engineering and construction methods at both secondary school level (Sampaio, Ferreira, Rosario, & Martins, 2010) as well as in Higher Education (Dinis, Carvalho, & Guimaraes, 2018). In terms of exposure to technology which is growing in use in industry, recent engagements by the authors with VR technology specialists from within the civil engineering and construction sector have strongly confirmed the growing commitment to adopting digital workflows, within which the use of VR - both to inform and enhance the design process as well as facilitate engagement with public and clients - is now seen as an integral part. Therefore, it would seem clear that exposure to these technologies, and the associated software tools, both as users and developers, is an essential part of current and future civil engineering teaching.

This study has explored only two applications of VR, and further research is required to understand where and when incorporation of VR can enhance Engineering education. There is a specific need to establish benefit beyond the novelty factor. This research suggests that

perception and skill enhancements are achievable through teaching with VR, and quantification of these should be explored.

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Theme Summary: Accreditation, Course Design & Co-design

Dealing with the fundamentals of course design and approval this section begins with a socio-political analysis of the Accreditation processes in the UK and Canada. Submitted by Klassen, University of Toronto, this work adopts a neo-pluralistic stance to compare and contrast key political and professional influences evident in the accreditation process within Engineering Education. Pointing to the importance given in both countries to the Washington Accord, Klassen offers a distinctive cross-cultural perspective.

Following this, the second paper in this section focuses on the challenges of designing the new Graduate Apprenticeship programmes within a Scottish Context. Tait et al, Robert Gordon University, provide a critical discussion of the problems faced in meeting the divergent demands of very different stakeholders whilst designing a programme that is aimed at graduate students in full time employment.

The impact of Industry 4.0 on Engineering Education is then discussed by Neaga, University of Wales, Trinity St David. Articulating the challenges of academic-industrial interdisciplinary working, Neaga suggests that Education 4.0 needs to embed the teaching of science, engineering and business within an adaptive learning environment.

Wood & Gibbs, University of Sheffield, provide much food for thought in the last paper in this section. Discussing the idea that students need to be 'true collaborators' in programme and course design, Wood & Gibbs draw upon the findings of an Action Research study to uncover how engineering students 'integrate learning'. They also provide advice on how best to promote student engagement within curriculum design.

Paper 1: The Politics of Accreditation: A Comparative Study of the Engineering Profession in Canada and the United Kingdom

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KEY WORDS: accreditation, profession, politics, neopluralism, comparison

ABSTRACT

Accreditation in engineering education is an important site for conversations among different groups in the profession about what is important to include in the curriculum, how it should be taught, and how to assess whether engineering graduates are ready to enter the realm of professional practice. While accreditation is often thought of as a neutral or benign bureaucratic process, this paper argues that it has political dimensions that should be considered. This paper investigates the politics of accreditation in engineering to uncover the different interest groups that actively shape engineering education. It compares Canada and the United Kingdom (UK) to point out differences in the structure of the profession as they relate to accreditation policy and implementation. Both countries are signatories to the Washington Accord, an international agreement that establishes mutual recognition of the substantial equivalence of engineering degrees. The findings show that professional bodies have significant influence, although they are organized along different lines based on historical path dependence. Analysis of the central accreditation bodies reveal ways in which the Washington Accord has strengthened these organizations by requiring a single signatory organization. Ultimately this paper contributes to a macro understanding of the structures of the engineering profession in different countries, and how these structures explain differences in implementation of accreditation policy.

INTRODUCTION

Universities and professional bodies share common aspirations of rationality, meritocracy and collegiality when it comes to making important decisions in their respective domains. This is heightened in engineering, where academic researchers search for science-based solutions to societal problems, and professional bodies cling to a notion of their duty to the

public (Buchanan, 1989; Millard, 1988; Riley, 2005). However, both universities and professional bodies are undeniably interest groups in a political arena, where power is contested and different interests clash in contexts of scarce resources (Bolman and Deal, 2003). The nature of these political dynamics is the central interest of this paper, which focuses on engineering in Canada and the United Kingdom.

BACKGROUND - ACCREDITATION

A crucial structural link between professional bodies and universities is accreditation, the process of periodically evaluating engineering degree programs to determine alignment with criteria set by accreditation boards (Hanrahan, 2009; Patil and Gray, 2009). Historically, decisions about accreditation criteria were mainly a matter of national policy, agreed upon by committees of professional engineers and academics. This changed in 1989 when accreditation bodies from six countries, including Canada and the UK, signed the Washington Accord, an international mobility agreement to align their engineering accreditation systems (Hanrahan, 2008). Initially, signatories to the Accord were acknowledging existing similarities in their approach to engineering education. However, in the late 1990s and early 2000s several leading signatories (the US and Australia) undertook major overhaul of their accreditation systems. These reform efforts centred around outcomes-based accreditation, which contrasted with the older inputs-focused system. Around this time, the Accord was also taking on many new countries, and formalizing its procedures, which created pressures for all signatories to follow suit. So, the Washington Accord became a powerful mechanism for spreading a model of accreditation premised on the assessment of student outcomes or graduate attributes to its growing membership of 19 countries (Lennon and Frank, 2014; Riley, 2012).

This study uses the adoption of outcomes-based accreditation as a way to understand the key actors in engineering accreditation, their sources of power, and the ways they use this to influence policy change in Canada and the UK. This is important because accreditation, and its requirements of particular modes of assessment, shape curriculum: what is taught, by whom, and how in engineering education. The Washington Accord was built on assumptions that all signatories have “substantially equivalent” engineering degrees: this is the basis for recognizing degrees from other countries and thus facilitating mobility (Patil and Codner, 2007). This study seeks to challenge that assumption by undertaking a systematic comparison of the architecture of the profession and the engineering education system in two countries that are signatories.

THEORETICAL FRAMEWORK - NEOPLURALISM

This paper treats stakeholders within engineering education as political actors. Drawing on a tradition of political science perspectives on educational policy analysis (McDonnell, 2009), I have chosen an explicit theoretical framework from political theory to underpin the analysis. Pluralism is based on the assumption that power is dispersed across different groups in society and not heavily concentrated in any one group (Dyck, 2004). This is useful because it emphasizes the broader political context in which engineering educators operate. Within the engineering profession, I draw on Dobratz, Waldner and Buzzells' definition of pluralism: "power is distributed among a 'plurality' of power centres... which include political parties, interest groups, voters, associations" (Dobratz et al., 2015, p. 11). These power centres are professional bodies, their national associations, employers, deans of engineering schools and engineering academics. As Ball and Peters explain, "decisions are seen as the outcome of bargaining between influential groups... [that] interact to produce an overall consensus, at the elite level and beyond" (Ball and Peters, 2005, p. 38). Because I am interested in accreditation policy and how outcomes-based accreditation has been adopted and adapted to the context of Canada and the UK, this approach helps focus on differences in power between groups, and how that might apply to decision-making.

Pluralism has been applied to many situations, within and beyond education. Within its home field of political science, the theory has been criticized for over-simplifying the complex dynamics of political interest groups. In response, a new generation of scholars have addressed some shortcomings in a range of approaches that have been captured under the umbrella of "neopluralism" (Lowery and Gray, 2004). Three main strengths of this approach are worth noting.

First, neopluralists "are attentive to a wide array of organizations seeking to influence the policy process" (Lowery and Gray, 2004, p. 168), including institutions, non-profit organizations, and associations. This is directly relevant to a study of accreditation policy, where the key interest groups range from professional bodies supported by legislation to voluntary associations representing engineering educators (e.g. Engineering Professors Council in the UK; National Council of Deans of Engineering and Applied Science in Canada). This is in contrast to older pluralist approaches that focus more on lobbyists and classical interest groups.

Second, neopluralists consider a deeper level of complex competition between organized interest groups, overcoming the tendency to oversimplify differences between haves and have nots, or to simply assume that powerful interest groups always get what they want. This analysis foregrounds situations where interest groups, which are largely aligned on most issues, suddenly are at odds on others, usually for a very particular policy (Lowery and Gray, 2004). This resonates with analysis of key groups in engineering such as academics

and practicing engineers: on the whole, they all support improving the position of the profession and preparing students for work, but they do occasionally clash over particular policy proposals.

Third, I adopt Lowery and Gray's neopluralist conception of politics as an influence production process with distinct stages. The stages are (1) formation and mobilization of interest organizations; (2) organizations enter a "population of interest organizations seeking to influence policy outcomes" (p. 164); (3) organizations attempt to actually exercise influence on policy or decision making; and (4) actual policy outcomes or implementation processes. This paper focuses mainly on the third stage, active attempts to influence policy, but includes some reflection on how the current influential organizations came to be, which speaks to the first stage.

Overall, neopluralism is a well-established approach within political science that is particularly helpful for analysing the tactics and political positioning of actors in educational policy. In this paper, it is applied to the professional field of engineering, which has its own unique features.

METHODOLOGY

This study looks at how national actors negotiate international agreements, using Canada and the United Kingdom as cases. Both were original signatories to the Washington Accord and yet have very different experiences with the introduction of new requirements for an outcomes-based accreditation system. The UK adopted outcomes-based accreditation quickly despite a complex proliferation of parallel professional bodies responsible for accreditation (Buchanan, 1985). Canada, despite being an original signatory, was one of the last countries to finally adopt outcomes-based accreditation, nearly 15 years after peer countries (Lennon and Frank, 2014), despite a seemingly simple organizational structure.

The specific research questions investigated are:

- 1) Whose interests are reflected in engineering accreditation policy in Canada and the United Kingdom?
- 2) How have key interest groups exerted influence to make or resist changes to the key policies and structures of engineering accreditation and the profession?

This paper draws from a larger study which includes five countries (Klassen, 2018). I analyse documents from the engineering education research literature, institutional websites, national independent reviews of the profession, and key public statements made by engineering interest groups. More information on the number of sources of each type for

each country is available (see Klassen, 2018 pp. 26-30). For the United Kingdom, the most important sources consulted are three major national and independent reviews of the structure and function of the engineering profession in the country, which include major recommendations for change (Finniston, 1980; Perkins, 2013; Uff, 2016). For Canada, the most relevant sources are documentation from a two-year consultation process led by the national representative body, Engineers Canada, to consider the future of engineering accreditation in the country (Culhane and Parent, 2016; Engineers Canada, 2018; MacQuarrie and Villeneuve, 2017). This consultation includes proposals for from key interest groups, along with the detailed presentations and minutes from board meetings where Engineers Canada voted on those proposals.

I also draw on a pair of important historical works that trace the early genesis of the engineering profession in each country. For Canada, Millard's (1988) *Canadian Engineers and the Politics of Professionalism, 1887-1922* traces the internal political dynamics that led to the formation of provincial regulatory bodies through passing ten nearly-identical licensing laws in each province. This meticulous historical text gives insight into the debates, dilemmas and assumptions that underpinned the professionalization of engineering in Canada. For the United Kingdom, Buchanan's (1989) *The Engineers: A history of the engineering profession in Britain, 1750-1914* illuminates the genesis of the professional engineering institutes in the UK. This book, alongside other relevant articles by Buchanan on the institutional proliferation of engineering in the UK (Buchanan, 1985) and the role of diaspora of British engineering (Buchanan, 1986) sheds light on why engineering has evolved such different structures for professional regulation and licensing in the two countries.

The theoretical framework used to draw together the findings from these various documents and historical texts is neopluralism (Lowery and Gray, 2004). I operationalize this by developing summary tables that show for the 4-6 major types of interest groups: (1) the main interests, (2) the sources of available power, and (3) the stage in the policy process where their power is most effective. This approach allows more direct comparison between the two countries.

The analysis started with an open coding of all relevant documents for each country. After initial coding, a set of common stakeholder types were identified across all five countries in the original study (Klassen, 2018). A second iteration of coding involved tracking the public statements made, and the governance documents underpinning key stakeholders, led to the interests and sources of power shown in the findings section. These findings are analysed through the lens of neopluralism to identify which stages in the policy influence process

were best aligned with each stakeholder's sources of power. Finally, an overall comparison shows similarities and differences across countries in terms of the most influential actors, the overall narrative of policy uptake, and historical explanations for why the profession is configured as it is.

There are several limitations to this methodological approach. First, the availability of documentation is highly uneven between the two countries: much more detailed information on accreditation policy changes is available for Canada, and much less information was found in the UK. This affected the unit of analysis, as the main policy change in Canada was adoption of outcomes-based accreditation (which occurred in the past decade) whereas in the UK the main policy proposal was amalgamation of professional engineering institutions, which has been ongoing for several decades, and is broader than accreditation.

FINDINGS

The main findings are presented in Tables 1 and 2. The major overall finding of this paper is that Canada's slow adoption of outcomes-based accreditation and the United Kingdom's resistance to organizational amalgamation of professional institutes are both explained by the power and interests of key influential groups within the engineering profession. In both countries, the most powerful actors are professional bodies, whose statutory powers grounded in legislation give them voting power over changes to policy. However, these professional bodies are structured along very different lines.

Canada is a federation, with responsibility for regulating professions delegated to the provinces, so each has its own provincial regulatory body, such as Professional Engineers Ontario (PEO) or the Order des Ingenieurs du Quebec (OIQ). These regulators focus narrowly on ensuring accreditation delivers engineering graduates that easily fit into existing licensing processes, and thus resisted the outcomes-based accreditation when it was first introduced because it might mean they would have to re-assess their systems. The accreditation board itself, CEAB, which has responsibility for setting policy, and leading implementation nationally, has been the main supporter of outcomes-based accreditation, as it is a requirement for the Washington Accord. Industry is largely absent from the policy process, except for informal influence as individual industrialists may happen to sit on the accreditation board (because of their professional affiliations, rather than their corporate ones). Engineering deans are highly organized in Canada, and the national council has been a visible presence in policy decision-making processes, arguing against a 'dual' model of accreditation that keeps the old bean-counting requirements of inputs while introducing the new and additional work for outcomes. Individual deans also have control over budgetary resources that will shape differences in how they implement outcomes-based accreditation

in their own schools. Finally, individual academics have no voice in policy decision-making at a national level, but they do retain the ability to resist or comply with outcomes at the level of their individual courses.

Table 1: Key Interest Groups in Canada

Interest group	Interests	Sources of Power	Stage in policy process where power is most effective
Provincial Regulatory Bodies	Ease of licensing; Caliber of engineers	Seat on Engineers Canada board; Licensing policies	Stage 3: influence decision-making (resist outcomes)
Accreditation Board (committee of Engineers Canada)	Keep the peace; Mutual recognition	Criteria interpretation statements; Accreditation decisions	Stage 3: influence decision-making (introduce outcomes) Stage 4: implementation (operate systems for outcomes at national level)
Industry	Work-ready graduates	Limited direct input;	None: informally might shape Stage 3 (decisions)
Deans (via national council, NCDEAS)	Minimize admin burden Maintain accreditation status	Seat on Engineers Canada board; Control over budgets for engineering schools	Stage 3: influence decision-making (fine with outcomes; resist inputs) Stage 4: implementation (resources for university systems for outcomes)
Academics	Flexibility in what is taught & how;	Discretion for how to implement and interpret LOs.	Stage 4: implementation (course-level adoption or resistance of outcomes)

Table 2: Key interest groups in the UK

Actor / Interest group	Interests	Sources of Power	Stage in policy process where power is most effective
Professional Engineering Institutes	Protect and grow membership; Promote knowledge, advance practice	Royal charter; Membership dues; Control of accreditation	Stage 3: influence decision-making (adopt outcomes); Stage 4: implementation (each PEI can interpret UK-SPEC differently)
Engineering Council UK (including Engineering Accreditation Board, as coordinator)	Keep the peace; Develop consistency and harmonization across PEIs; Improve efficiency	Has its own royal charter; Oversees accreditation, sets general framework; Guidelines for PEIs	Stage 3: influence decision-making (introduce outcomes via Washington Accord) Stage 4: implementation (attempt to align practice across PEIs, through EAB)
Industry	Work-ready graduates;	Via PEIs and industry advisory boards	Stage 4: implementation (give input via advisory boards on how to interpret outcomes)
Engineering Professors Council (representing academics)	Profile and influence of professors; Best practices exchange;	No formal power; Informal relationships with PEIs and RAEng	Stage 4: Implementation (program/course level)
Deans	Maintain accreditation status; Enrolment #s	No (visible) formal association or organization	Stage 4: Implementation (school level)

In the United Kingdom, professional bodies are split along disciplinary lines, from the Institution of Civil Engineers (ICE) to the Institution of Chemical Engineers (IChemE). More than twenty different professional institutes are licensed by the Engineering Council to accredit, license and register engineers. There is no clear record of resistance to outcomes-based accreditation by the UK PEIs; this is best explained by a broader shift in professional and vocational qualifications towards competence-based assessment that pre-dated the Washington Accord, meaning engineering professional bodies were “ahead” of the policy

shift to accreditation. On the other hand, there have been numerous, high-profile attempts to reorganize the profession by merging the disciplinary institutions – which has been strongly resisted by small and large professional bodies alike. The Engineering Council is the umbrella organization for the profession and also the Washington Accord signatory; it is responsible for transitioning UK engineering accreditation to an outcomes-based system. A tension in the implementation of outcomes in the UK (which has been in place for over 15 years) is the autonomy of professional bodies, and the desires for consistency from the Engineering Council and the Engineering Accreditation Board (a coordinating body that provides policy guidance). Most of the interesting dynamics regarding outcomes-based accreditation in the UK centre around implementation, this is reflected in the fact that most interest groups only have power in this stage of the process: employers, deans and academics themselves. Employers from industry mainly influence uptake through industry advisory boards, where they shed light on specific graduate attributes or competencies for their industry. Deans mediate implementation through the allocation of resources and structuring of roles for accreditation; whilst individual academics can support or resist at the course level, much like in Canada.

DISCUSSION AND COMPARISON

Powerful interest groups have resisted changes to the status quo in their respective contexts: the Canadian provincial regulators blocked a proposal by the deans to reduce content requirements in accreditation (Klassen, 2017), while the UK professional institutes have blocked repeated calls for consolidation and amalgamation in the name of protecting their disciplinary identities and territory (Uff, 2016).

The Washington Accord itself is a powerful global influence shaping accreditation policy and politics in both countries. The Accord assumes the existence of a single, powerful accreditation board at the national level based on the strong early influence of the models from Australia and the United States. This policy assumption has infiltrated the political arenas of engineering accreditation in Canada and the UK, and is increasing the power of the respective national accreditation boards, which now have oversight over the new outcomes-based accreditation systems. In Canada, the Canadian Engineering Accreditation Board, a committee of Engineers Canada, has more direct control over accreditation. It oversees and guides accreditation across all disciplines of engineering in the country. The equivalent body in the UK, the Engineering Council and its Engineering Accreditation Board, has control over policy but less influence on implementation – given the delegation of accreditation to professional bodies themselves. Whilst drawing on the sector-wide framework (AHEP and UK-SPEC) each is allowed to add their own requirements, and each interprets the core

framework slightly differently.

It is crucial to differentiate between interest groups' influence on policy changes (i.e. supporting or resisting the adoption of outcomes-based accreditation) and their influence on policy implementation. So far, the analysis has focused mostly on the former, which identifies professional bodies as the most influential actor. However, when it comes to implementation, power shifts to engineering academics in universities. From how they organize their courses, to decision making about curriculum governance, to broad strategy set by deans, academics have some discretion in how they interpret and implement outcomes-based accreditation. They also constitute the majority of accreditation panels that visit other schools and programs, through their affiliation with their respective professional bodies. Recent empirical work in Canada shows major differences across universities in the response to outcomes-based accreditation in engineering, ranging from avoidance to compliance to enthusiastic adoption (Klassen and Sá, 2018).

This study illustrates neopluralist theory at its best and worst. On the one hand, elite decision makers in national engineering associations are seeking out and considering the perspectives of other interest groups. On the other hand, in both cases, the voting members on the boards of elite professional bodies have decided to stick with the status quo which aligns with their existing processes and avoids a complete overhaul of licensing and registration for their organizations. Traditional pluralism fails to explain the absence of the voice of individual engineering academics, while neopluralism turns our attention to the processes of interest group formation and entry into the population of other organized interests. In the UK, academics are organized under the Engineering Professors' Council but an equivalent body does not exist in Canada. Some might argue that the Canadian deans represent the interests of the academics they lead, but this isn't borne out by Canadian research on how contracts and collective bargaining agreements align deans much more with central administration and management than rank and file academics (Boyko and Jones, 2010). This administrative interest of deans is illustrated in the specific arguments the Canadian deans make about the administrative and financial burdens of outcomes-based accreditation (NCDEAS, 2016). These types of organizations are easily taken for granted by those who participate in them, but from a research perspective they are under-theorized and worthy of further study.

A key finding from this study is the rubber meets the road in implementation of outcomes-based accreditation in different professional bodies and different universities. Investigating this process by interviewing key academics involved in curriculum governance, preparing for accreditation, and leading visits to other institutions would illuminate how engineering schools interpret and respond to expectations for outcomes-based accreditation.

CONCLUSIONS

This paper focuses on the broader structure of the engineering profession, which might seem far away from the pressing realities of engineering educators tasked with drafting learning outcomes, designing modules, and adapting assessment to keep in line with both professional requirements and university priorities. The benefit of this broader view is to explore the structural and political sources of current trends, and to look for opportunities for improvement. The findings highlights the links between engineering education, accreditation and professional status as recognized by the appropriate bodies. This offers a macro view of the different interests, forces and powerful actors shaping engineering education that are not always visible from within an engineering school, department or classroom.

This paper unpacks critical inter-organizational dynamics at the interface of universities and professional bodies. Neopluralism provided the core entry point into the dynamics of interest group formation, interaction and influence on policy decisions. This approach can be adopted in a flexible manner to undertake relevant comparative studies of other countries who have signed the Washington Accord and adopted outcomes-based accreditation. This would enable insights on how different legal and institutional configurations of the profession shape the politics of accreditation in different contexts.

Ultimately this paper shows the value of using political theories to analyse dynamics within engineering education. It highlights the stages of the policy process where different actors (e.g. professional bodies vs. deans. vs. academics) can have influence over accreditation and education. Recommendations for engineering educators include expanding the visibility and legitimacy of national engineering education associations; further investigating the role of different professional institutes in shaping the curriculum and the possible role of academics in directing those institutes themselves. Recommendations for future research include more original interviews and empirical work to explore implementation dynamics in different contexts.

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Paper 2: Development of Scottish Engineering Graduate Apprenticeships: Concept-Validation-Launch

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KEY WORDS: [Graduate Apprenticeships, Engineering, Course Development]

ABSTRACT

Robert Gordon University (RGU) was successful in their application to Skills Development Scotland (SDS) for the design and delivery of seven Graduate Apprenticeships (GAs). Two of these, namely BEng Engineering: Design and Manufacture and BEng Engineering: Instrumentation Measurement and Control, have been developed over the past year and officially launched in September 2018. This paper summarises the journey and challenges of designing degree level engineering courses for a full-time workforce, with additional partners not usually associated with course development. Elements of the course structure are explained and suggestions for future engineering education research are put forward.

INTRODUCTION

The Scottish Government committed to increasing the number of work-based learning opportunities available through Apprenticeship programmes. (Skills Development Scotland, 2018). This was to be achieved through the continued development of Foundation and Modern Apprenticeships but also by the development of Graduate Apprenticeships.

Funded by SDS, the Graduate Apprenticeships (GAs) are an extension of the apprenticeship model to a degree-seeking programme with potential for professional body accreditation. Frameworks for each GA course were designed by Technical Expert Groups for SDS.

GAs are intended to provide work-based learning opportunities for employees and have been developed in partnership with industry and the Further and Higher education sector. GAs combine academic knowledge with work-based learning to enable students to become more effective and productive in the workplace.

The School of Engineering at RGU has been delivering content in e-learning and blended learning formats since 2002. Its online MSc programmes have been taken successfully by students worldwide. The School built on this experience both in online course delivery and in undergraduate MEng Fast Track provision (4 year MEng, unique in Scotland) to develop the model for delivery of the GAs.

BACKGROUND

The Scottish Government committed to increasing the number of work-based learning opportunities available through Apprenticeship programmes with a view to having 30,000 Modern Apprentices (including GAs) by 2020. (Skills Development Scotland, 2018). This is to be achieved through the continued development of Foundation and Modern Apprenticeships and by the introduction and development of GAs. One main requirement was to develop an apprenticeship that could be completed in 4 years and be suitable for professional body accreditation.

Prior to engaging with GAs, the School of Engineering at RGU had been delivering BEng and MEng undergraduate courses with a strong practical approach. Hands on experiences within the School are further enhanced by industry placements and project work, both individual and group. The CDIO model (Conceive, Design, Implement, Operate) (CDIO, 2018) while not underpinning the courses officially is evident in a number of key “design and build” modules. The courses are supported by an industry board who contribute at key evaluation points in the course duration. Metaskills are developed through work embedded in modules and through placements.

A key aspect of RGU’s course design was to ensure students from anywhere in Scotland could participate to maximise recruitment potential. Additionally, it was decided that employers should be closely involved with the specification and delivery of work-based learning activities to support the learning and development of students. Indeed, the role of the employer is critical to the success of an apprentice (Ismail et al 2018.) Strong

engagement from senior management in the institution, including significant resourcing to support development empowered Schools to deliver robust yet forward-looking course designs.

DEVELOPING A GRADUATE APPRENTICESHIP FOR ENGINEERING

The GA Frameworks (SDS, 2017) were released for the bidding process in October 2017. The bidding process ran alongside development of the course due to the time limit of a September 2018 start. The School established a GA development team comprising a GA lead, two course leaders, two engineering applications supervisors and an administrative assistant. Initially, information review and scoping was carried out by reviewing literature on work-based learning and current apprenticeship programmes. Industry connections were consulted in a series of events to allow industry contribution and collaboration.

The frameworks issued by Skills Development Scotland were mapped to existing capability and gaps identified. Areas of commonality were identified, and personnel appointed to lead them for all GAs in the university. A further mapping was carried out to establish the SCQF levels of each desired learning outcome.

A team led by the Department for Enhancement of Learning Teaching and Access (DELTA) developed areas that were common to all GAs across the institution. This allowed for commonality in areas such as course documentation structure, processes and central student support.

Work-based learning principles that were desired from providers included the concept that learning in work must be fully integrated into delivery and assessment, and not achieved through add-on components (Skills Development Scotland, 2016). This is supported by a combination of a reflective experiential pedagogical approach (Schon, 1983) and learner-centred design through a learning plan negotiated with and supported by both mentor and the School of Engineering.

Rouvrais et al (2018) noted that in the French engineering community work-based learning is a high value approach which supports student autonomy. Additionally, through work carried out in the School on retention of distance learners (McCafferty, 2010) the notion of volition and motivation in learning (Diemann and Bastiaens, 2010), (Keller, 2010) and their impact was considered in the curriculum design.

Establishing fit for purpose assessment (Nicol and Macfarlane-Dick (2006) was also important as given the competing demands of a working student, there would be little room for activities not considered critical to the degree. Authentic assessment is a key feature of

work-based learning (Kettle, 2013) and therefore cognisance of workplace activities comparable to university activities needed to be recognised.

Courses would be required to be highly flexible, allowing for entry and an exit with award at numerous points. Sandwich or block release course models were not desirable and so a highly integrated model was developed to maximise opportunities for using workplace experience to meet learning outcomes.

Specifically, students would be encouraged to identify learning opportunities, consider the learning objectives associated with these and reflect upon these experiences to consolidate and apply learning. With regard to work-based learning activities, employers would be guided in the identification of suitable activities and projects, and workplace mentors would be supported in aiding students to capture and reflect on learning from the workplace and encourage the unification of knowledge and experience from the work and university spheres.

In order to achieve learning primarily in the workplace, the delivery model includes the student, the university and the workplace mentor (industry).

The initial planning stage included defining the course and module structure. A mapping of GA learning outcomes to existing provision was carried out in the first instance to establish what might be adapted for GA delivery. Gaps that had been identified were addressed through consultation with industry partners, professional bodies and subject experts. A set of expectations for students and employers in terms of workload was outlined. Methods of student support were identified, including a list of desired qualities in workplace mentors.

At the earliest opportunity, industry contacts were established in the local area and a series of consultation events were held. These events included consulting with professional bodies (Institute of Instrumentation Measurement and Control), chartered engineers and a number of employers from different types of companies including SMEs.

COURSE STRUCTURE

As required by Skills Development Scotland, the BEng courses are to be delivered over four years with apprentices undertaking 120 credits per year over 12 months. Learning in the workplace will be used to make use of workplace tasks that the apprentice undertakes.

Each year comprises four 30 credit modules which are delivered sequentially. In the existing full-time undergraduate delivery students undertake 4 15 credit modules per semester. Sequential delivery was chosen to allow focus on a particular topic, which has worked well

in the School's distance learning provision where students have high levels of competing demands. Students develop a portfolio of evidence towards learning outcomes. The figures below depict the modules for each stage. The first three modules are common to both courses.

Figure 1. Course Overview Design and Manufacture

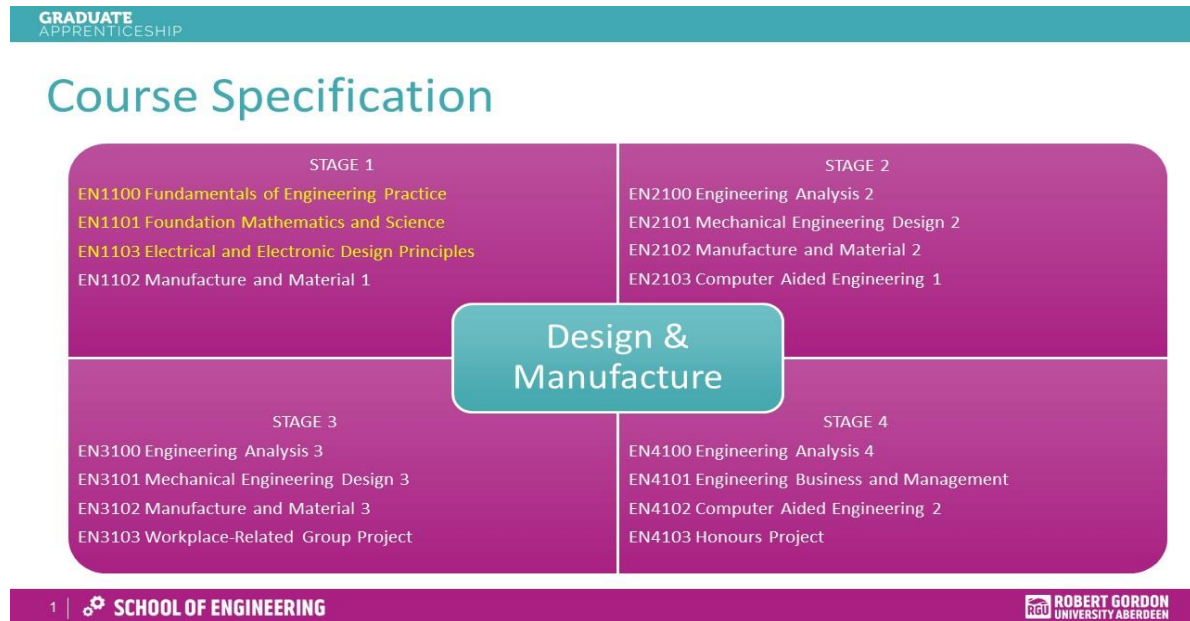
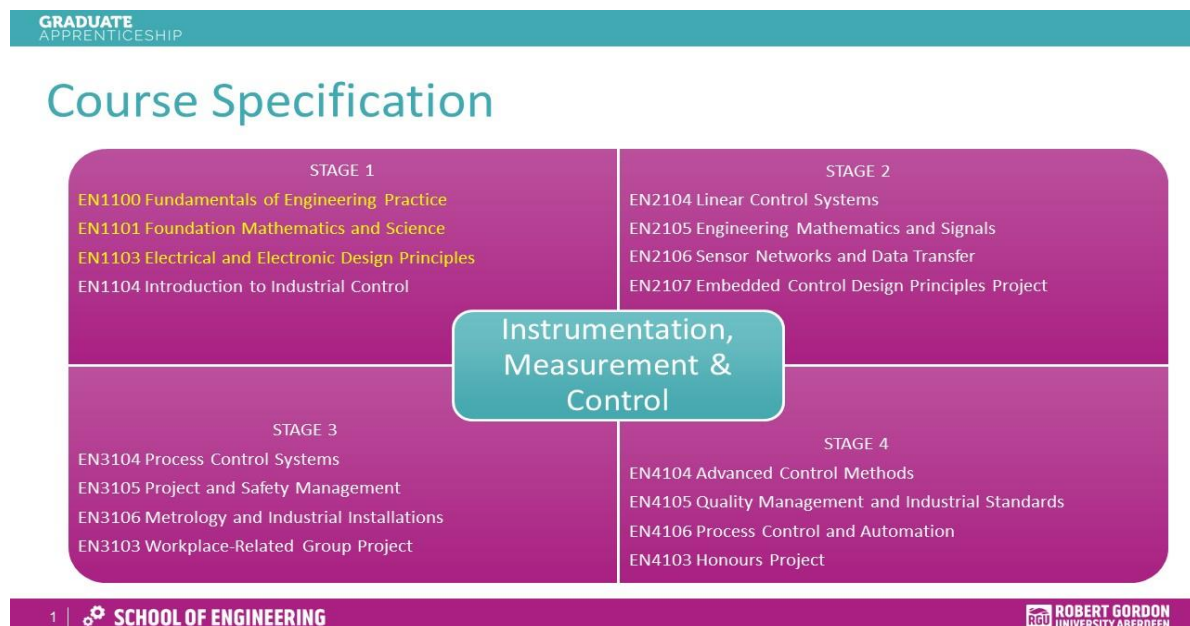


Figure 2. Course Overview Instrumentation and Control



The university provides all the learning material, technical and academic support through a virtual campus and other forms of communication. Workplace mentors, appointed by employers and supported by the University, work with students to create individual learning plans which outline the shadowing, observation, training, work activities and project opportunities which students would undertake in the workplace. These learning plans would be reviewed by the School of Engineering to ensure that the required employer contextualisation is appropriate for the level of study.

Workplace mentors will ideally be chartered engineers and be positioned to enable access to learning opportunities with the student's employer or with an appropriate alternative. Workplace mentors will also receive CPD through informal and formal support and be encouraged to work towards Associate Fellowship through Advance HE through the university's existing framework.

The student would have regular tripartite review meetings with their academic tutor and mentor to discuss their progress including issues relating to portfolio work as well as their development goals and aspirations. These meetings should highlight areas for development that would allow for planning and mitigation. Students would be expected to use an e-portfolio to record their professional and personal development. In addition, it is anticipated that students will undertake the majority of their learning and assessment-related activities in the workplace.

The joint effort between support departments, the Schools and employers resulted in the successful validation of the seven GAs on the 6th June 2018. Feedback from the validation panel included commendations for clear feedback strategies, diverse content, flexibility, and the range of supportive collaboration.

50 students from 20 companies were recruited to the Engineering courses. The first module has been delivered and most (45) students successfully submitted their first e-portfolio by the agreed deadline. The remaining students are being supported by an extension to the deadline and help from module tutors.

KEY FINDINGS

Both Engineering GAs have been running since September 2018. The first module of 30 credits – Fundamentals of Engineering Practice is complete and submissions being assessed.

Strong engagement of employers with the course design, adapted methods of delivery and support were combined to deliver the GA. Many GA students were already in employment,

but some are newly appointed employees. This diverse cohort brings challenges and opportunities. Building and maintaining the tripartite relationship is essential.

There have been a number of challenges in developing the GAs:

- The need for maths at SCQF 6 or equivalent prior to entry
- The development of appropriate learning materials which allowed students to contextualise knowledge to their place of work
- Development of alternative acceptable entry requirements for applicants without traditional qualifications
- Supporting and developing learning plans for a diverse cohort
- Supporting industry mentors and employers
- Employers need to recognise the need to give the GA students time in the workplace for study as well as identifying work-based learning opportunities.
- Workload balance between work-based learning, study at work and homework.

The development of the GAs was made possible by building on established and new relationships with employers across Scotland. Feedback overall has been positive and a recent highlight was the successful mentors induction, further developing these relationships. However, there is a need for employers to more fully recognise the value of supporting their staff to learn and the importance of developing a learning culture within their companies.

“Employers must realise that it is a sound investment to allow workers to spend time on learning activities which will reap long-term benefits by up-skilling and motivating their staff. The culture needs to permeate all levels in the organisation so that workers are comfortable learning rather than working, and that colleagues do not regard them as less productive.”
(Ball and Manwaring, 2010, p16).

While some companies have adopted a reasonably hands-off approach in terms of content development, a small number of companies have become extremely active in supporting GA delivery and suggesting innovative developments and the School is moving forward in partnership with both students and their employers.

DISCUSSION

At the application stage, the lack of Higher Maths (SCQF level 6) posed a real challenge. Applicants with a wide range of experiences were registering their interest however the School had concerns that not having a maths qualification would seriously hamper progression through the course.

An interview process was introduced during the recruitment for the 1st year to allow of the possibility of entry for those who did not have a higher maths or equivalent qualification. This was partially successful in that some applicants were accepted on to the GA following interview. A free preparatory maths module has been developed to support students required to be interviewed. However, advice to potential candidates for the GA remains to be to seek a maths qualification prior to application.

At the moment, modules run sequentially. As the course progressed concurrent modules over a longer period may be considered. Feedback from some employers has highlighted the need to make information available sooner than had been planned. For example, assessment plans have been requested for future modules so that mentors and students can look ahead more easily and potentially have more opportunity to provide workplace activities supporting learning outcomes.

GAs may have an impact on evening-class courses which target those in full-time employment. However, at the moment the evening-classes delivered by the School are to BSc level rather than BEng. Should the GAs prove successful, elements of the model may be utilised in part-time provision to enhance student experience.

CONCLUSIONS & RECOMMENDATIONS

The journey from concept to launch has been summarised in this practice paper. Key points and challenges have been highlighted. While the development of the GAs has been a significant learning curve for the School of Engineering, it presents opportunity for engineering education research. To this end the School is considering research looking at the effectiveness of using non-traditional learning methods (workplace-based learning) in the workplace. There is potential for research activity to:

- establish a collective understanding of whether and how such programmes can be adequately supported and assessed;
- the conditions (external and internal) that might influence the success of these initiatives for different types of students and different employers;
- aligning level learning outcomes with workplace experiences to develop a standardised approach to recognition of learning;
- work study life balance should be monitored to ensure GA students have the support they need.

Further to this work, a comparison of the GA delivery method and the full-time delivery method should be carried out, with a view to enhancing practice. Research methods that may be appropriate could include survey, focus groups, and semi-structured interviews.

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Paper 3: Petroleum Engineering: A collaboration between Academia and Industry

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KEY WORDS: Petroleum Engineering, Oil and Gas Industry, Petroleum Engineering Graduates, Industry Collaboration, Faculty and Teaching.

ABSTRACT

Petroleum Engineering remains an important area of study in our world and would continue to do so for the foreseeable future even with the advent of renewable energy and drive towards a more sustainable energy source. With this in mind, maximising the relationship that currently exist between the academia and industry is very important in order to produce the next generation of petroleum experts capable of providing innovation and change to drive this sector towards meeting the energy demands of the world. This paper provides a reflective analysis on the processes needed by both academia and industry to ensure they both work towards empowering future petroleum engineers to maximise the opportunities within this sector. By reviewing the academic curriculum and skills needed by petroleum engineers and also examining the limitations currently existing in the relationship between the oil and gas industry and academics, the paper offers ways by which a mutually beneficial relationship could be achieved.

INTRODUCTION

“Petroleum engineers make the world run.” This proud quote, is extracted from the Society of Petroleum Engineers’ website indicates how highly regarded a career in Petroleum Engineering is considered. This means that, it is very important for the educational process to work effectively to prepare the next generation of engineers to fulfil the industry needs.

As Petroleum Engineering completes a century in the academic realms, the rapid evolution of the petroleum industry and its technology has necessitated a concurrent change in the Petroleum Engineering education process. Whereas in the past, oil industry employers expected recent graduates to be competent ‘plug-and-chug’ engineers who would immediately contribute and fit into the daily work environment, modern day employers have additional requirements. They still want technically competent engineers with a solid understanding of the various industry technologies, but are also asking for more.

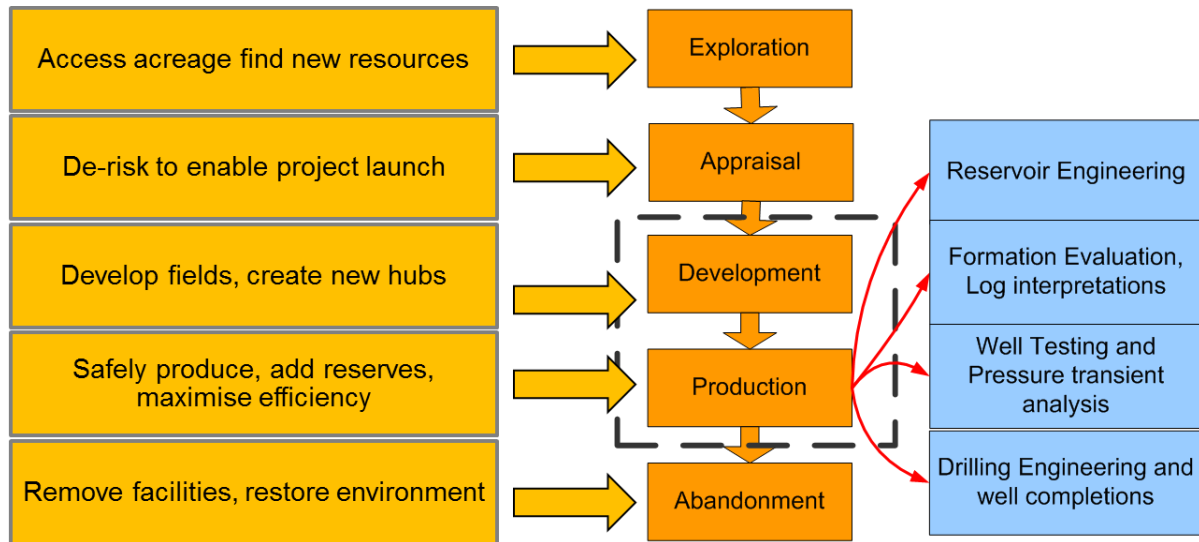
Educating and preparing engineers in general for the 21st Century requires adequate changes in the style of teaching and demonstrating knowledge, concepts and their application under complex conditions. The Energy industry is undergoing fundamental changes globally, coupled with the change in higher education landscape and funding, requiring a transformation in the classroom in order to prepare future engineers for contemporary issues in all aspects of oil and gas industry, especially exploration and production. Experience has shown that traditional teaching through lecturing generally results in students acquiring/ remembering less than 50% of the information delivered in the lecture (Cunha, 2004). Several factors contribute to such ineffective teaching/learning method. In this paper examinations and analysis of these factors are discussed to offer some tools to engineering professors who wish to become better teachers and to university administrators who wish to improve the quality of Petroleum Engineering teaching.

LITERATURE REVIEW

Petroleum Engineering as defined by University of Texas, a leading institute in petroleum, is a combination of innovation, exploration and expansion. that provides the major fuel for the world and the building blocks for every other profession to effectively carry out its work. University of Portsmouth, another leading institute, defines Petroleum Engineering as an engineering discipline concerned with mainly subsurface activities related to the production of hydrocarbon with the application of “engineering” to the exploration, drilling and production of oil & gas. Petroleum Engineering is associated with the “UPSTREAM” sector of

the oil & gas industry and is underpinned by the extraction of hydrocarbon whiles maximising oil and gas recovery at minimum cost in a safe way as highlighted in Figure 1.

Figure 1 Various disciplines within Petroleum Engineering sector



In any discussion of Petroleum Engineering Education, many questions arise concerning the best procedure to pursue and the best curriculum to follow in order that the young graduate may be as well-equipped as possible to enter the petroleum industry in an engineering capacity. It is clear that what may seem to be the best curriculum in Petroleum Engineering today may not be the best course of study for the future. Education in Petroleum Engineering is relatively new, and considerable evolution has been witnessed since the establishment of the first department at the University of Pittsburgh in 1912 (Cunha, 2004). The needs of the industry and the development of engineers to meet the changing order of events will dictate the relative emphasis which must be placed upon the so-called fundamentals and their application in the specialized course.

AIM AND OBJECTIVES

This paper seeks to examine the key relationship between academia and industry and to reevaluate the ways by which each player could help enhance petroleum engineering. It also Reflects on the best practices within the academia and how they can improve the standard of tuition in petroleum engineering to ensure students are able to maximise their potential.

DISCUSSION

Petroleum Engineering Skills

The rapid evolution of the petroleum industry and its technology has necessitated a concurrent change in the Petroleum Engineering education process. In the past oil industry employers expected recent graduates to be competent 'plug-and-chug' engineers who would immediately contribute and fit into the daily work environment, Modern day employers have additional requirements. They still want technically competent engineers with a solid understanding of the various industry technologies, but are also asking for more. Knowledgeable, informed, intellectually curious, responsible, self-aware and self-motivated, independent learners set for success future careers are listed as the hallmarks of a graduate for Petroleum Engineering roles. Basic skills for a petroleum engineer, besides mastering fundamentals of mathematics, physics and chemistry, will include:

- Geology;
- Well drilling & completion technology;
- Formation evaluation;
- Oil and gas production technology;
- Properties of reservoir rocks;
- Properties of reservoir fluids;
- Fluid flow in porous media;
- Well testing analysis
- Reservoir performance prediction
- Enhanced oil recovery techniques
- Field economic analysis

Curriculum and Graduate attribute

Petroleum Engineering courses must include certain attributes in order to meet the demands of employers when assessing the skills of graduates. The curriculum must include the following points in its design for cradle to Job cycle as detailed in figure 2.

- Have a critical and reflective knowledge and understanding of their subject, with both the ability and readiness to question its principles, practices and boundaries.
- Think independently, analytically and creatively, and engage imaginatively with new areas of investigation within and across discipline boundaries.

- Be able to synthesise new and existing knowledge to generate ideas and develop creative solutions of benefit to the economy and society.
- Be intellectually curious, embrace challenges and seize opportunities for development.
- Be able to locate, access and critically engage with information, using current and emerging digital technologies.
- Be informed citizens, with a sense of responsibility allied to a commitment to ethical practice and social justice issues, such as equality, respect and sustainability.
- Be effective team players, able to provide leadership and to support the success of others.
- Be able to communicate clearly and effectively, in a range of forms and to different audiences.
- Have an enterprising spirit, bringing innovation and productivity to the groups and communities to which they belong.
- Be able to work in a range of environments, responding positively to new situations by being aware, flexible, adaptable and realistic in their expectations.
- Be proactive in recognising and addressing personal development needs, and able to make informed career decisions

Figure 2 Curriculum attributes

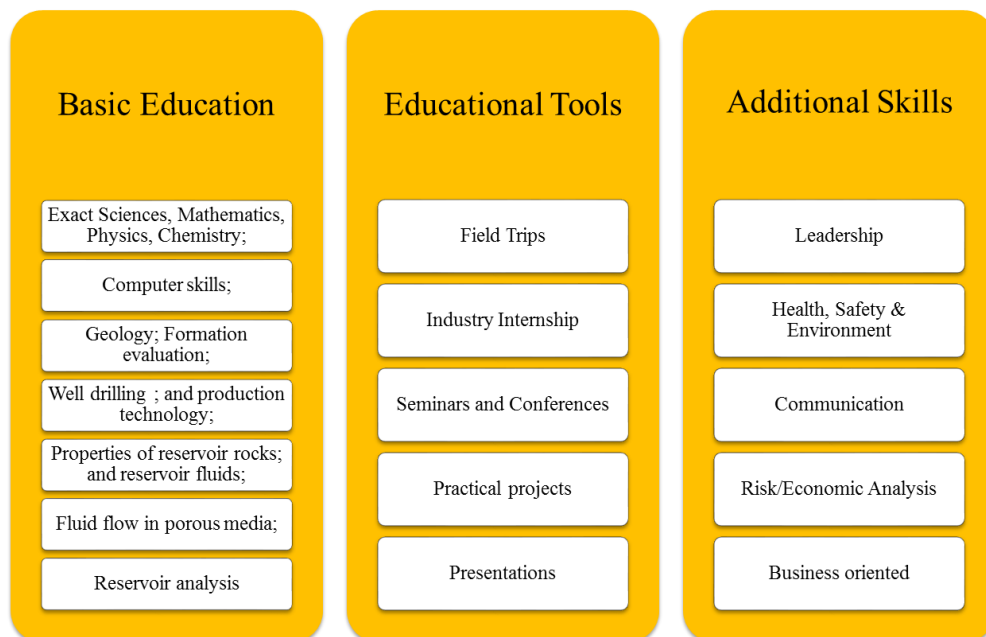


Figure 3 Characteristics of an Ideal Petroleum Engineering Graduate



Figure 3 shows the characteristics of an ideal Petroleum Engineering student. It is probably unrealistic to expect to find the aforesaid set of skills on a recent graduate. However, as a goal, Petroleum Engineering education should provide the students with the means to use their technical background and personal qualification to acquire those skills.

Faculty and Teaching

The transformation of empirical knowledge into practice through a rigorous day to day problem solving activity that encompasses intuitive, reflective and moral perspectives of action, allows teachers to enact professional practice and enables tacit understanding and constructing from our own patterns of action. Also, this routine reflection on previous experiences, combined with technical and ethical qualities, brings professional knowledge into decision making in problematic, troubling and uncertain situations that can be reframed into different situations with a new meaning (Hoyle & John, 1995). Professional teachers in Petroleum Engineering must have and create social, industrial and educational impact, alongside other elements involved in professional practice such as autonomy to act and

judgements in the best interest of students, responsibility and accountability, their main focus is preparing the next generation of petroleum engineers capable to use new technologies and more qualified in innovating directions in management of oil and gas projects (Hoyle & John, 1995). Delivering high class teaching is paramount to deploy knowledge in complex and uniquely distinct classroom settings, and requires a clear understating of classroom practice along with highly skilled expertise and high quality, uninterrupted and solid engagement with students. The use and the development of research to assess and critique own practice combined with peer's observations is a good route to acquiring mastery in the classroom to improve practice (Furlong, 2013).

An important aspect of our own development, as members of the Petroleum Engineering faculty, is related to the development of our ability to understand situations and dilemmas that can lead to changes in our working relationships and professional practice. This development is not only an academic exercise to enrich our own particular subject knowledge, also encompasses adapting a critical and reflective approach into our practice to further develop competence and ultimately to crave our professional identity as faculty (Brock, 2015.).

Teaching Petroleum Engineering is not only about using endless, and sometimes, boring and disengaging presentations just to pass complex concepts and specific subject knowledge to students; but instead is about integrating theory and practice by tailoring theoretical and research-based knowledge to fit specific practical situations through a perspective more firmly rooted in the realities of practice, in which the professional knowledge base offers insights but no direct lines of actions for dealing with specific practice situations, which is the essence of reflective practice(Thompson & Pascal, 2012).

So aside from the curriculum content, a critical look at teaching methodology must be reviewed. Teaching courses using the same way that is taught over 50 years ago with the exceptions of replacing the black board and chalk with PowerPoint presentations is not a good way. Educational and teaching methods are being influenced by new emerging technologies (software, on-line quiz, 3D animations, documentary videos, etc.) and the content of Petroleum Engineering programmes needs to dynamically adapt to the world of the millennium or face the risk of extinction. Petroleum Engineering faculty as well as professionals in the industry have been challenged to "learn to listen first, understand issues and concerns, then respond by sharing facts, doing additional research, reporting progress and continuously improving" (Smith et al., 2017).

Professional Petroleum Engineering faculty should be autonomous knowledgeable practitioners with moral, social and environmental responsibility accountable for the development and improvement of their academic and professional knowledge and are fully aware of student's learning needs and industry's skills necessities.

The teaching model of class room delivery of course materials and testing learning outcomes by exams must be reflected upon and more practical elements and problem based learning provided.

Many academic are teaching their courses in complete isolation from others with no linkage of the material taught in relation to other courses, to the overall objectives of the degree, and most importantly to practical and field applications.

- Young and mid-career faculty, who is in line for promotion, are always more busy and focused on research. Young faculty members are usually unable to relate the courses they teach to practical and field applications.
- Senior faculty, professors, on the other hand usually have many graduate students, funded research projects, administration and management paperwork made them far removed from undergraduate students interactions beyond lecture time.
- Retired industrialist who are willing to spend time with student on war stories but disconnected from curriculum requirement.

Industry Collaboration

The recent downturn in the oil & gas industry has forced many companies to work on developing their internal systems and corporate social responsibility. This has led to the number of jobs being reduced and reorganization of the existing staff is being undertaken to improve efficiency. The challenge is further raised when a balancing act needs to be played to manage the availability of experienced staff and the less experienced young professionals to mitigate everyday complex challenges. To avoid such situations in the future some steps need to be taken now. It is clear that steps taken today may not provide us with an instant solution but would protect the industry against the unseen challenges of the future. Questions need to be raised on the finding the right solutions to the challenges faced by the industry as well as how those challenges could be overcome.

The solution is obvious from the academic side and involves embarking on less well-known ways to collaborate with industry. The suggestions put forth here may not attribute a lot in short term, but in the long term will definitely contribute in solving few of the above

challenges. The continuous training of professionals with latest technology is always the best solution for the short term. However, for the long term the most suitable way will be to collaborate with universities, the very place from where the upcoming talent is born and honed for their skill set development. Furthermore this will provide the universities with an additional input to enhance their courses and align it better with industrial requirements. The main categories where companies can contribute and gain new talent can be grouped under the following:

- KTP (knowledge transfer partnership)
- MReS (Masters of Research)
- Contribution to courses (PhDs, MSc & M/BEng) with Industrial Projects and Data
- Internships
- Software packages, equipment donations and infrastructure fieldtrips

Knowledge Transfer Partnership (KTP) is a part government-funded programme to encourage collaboration between businesses and universities in the United Kingdom. KTP was launched in 2003 and the programme is funded by 17 public sector organisations. There are approximately 1,000 concurrent programmes at any one point in time and KTP works with over 140 universities, colleges, and research organisations across the UK. A (KTP) is a three-way project between an academic, a business and a recently qualified person (known as the Associate).

The aim of each KTP programme is to help businesses improve their competitiveness and productivity through the better use of skills, knowledge, technology and innovation. As a part-government funded programme, a company entering into a KTP programme contributes between 33-50 % of the project cost, with the government contributing to the rest. The average annual project costs are approximately £60,000. This package includes the associate's salary, travel budget, personal development budget, academic input, expertise, and administrative support.

KTP provides leading academics with the opportunity to:

- Apply knowledge and expertise to important businesses problems
- Develop business relevant teaching and research material

- Identify new research themes in undergraduate and post-graduate projects
- Publish high quality journal and conference papers
- Gain an improved understanding of business requirements and operations
- Participate in rewarding and ongoing collaboration with innovative businesses
- Supervise and act as mentors for past graduates working on business based projects

What can KTP offer your business?

- Access to qualified people to spearhead new projects
- Access to experts who can help take your business forward
- Develop innovative solutions to help your business grow
- Increase your competitive advantage
- Improve your performance/business operations
- Increase profitability

Master of Research is a Part-time/full time degree that provides an excellent opportunity for professionals to undertake research and is increasingly popular within a number of the Russell Group Universities. Professionals have the opportunity to focus their research interests on one or two areas, allowing them to become an expert in specific subject knowledge. It also provides the environment to translate their findings into research related outputs. Such research can also be undertaken by professionals based on their area of expertise to gain a degree for their career enhancement including such activities as: preparation of peer review publications, critical reviews, grant applications, conference presentations or intellectual property submission.

Contribution to courses (PhDs, MSc & M/BEng) with industrial projects could be one of the most proactive ways of starting industry and university collaboration. It is a direct collaboration where a company can engage with a student while performing a final year or a master's project. It can be a literature research based project or practical one, where any sensitive data can be protected with confidentiality agreements. It is win-win collaboration where skills, innovation and enthusiasm of a student can be assessed while performing their project. Through this collaboration students can develop business acumen and improve professionalism, while working on a project with real data that can maximise challenges and enhances the learning experience.

The industry and university students always value internships greatly. It provides an opportunity for the student to move from university-based theoretical knowledge to practical application. Further, it introduces students to the fast paced challenging professional environment. This is an on-going practice that is utilised by a number of organisations. In the past few years we have seen a steady decline in the number of internships being offered. It is understandable considering the market volatility of the past few years followed by a sharp decline in the oil prices making things difficult.

However, a few innovative ideas can really help to boost enthusiasm. An attractive alternate could be something similar to the “Shell Eco-marathon competition”, where teams of students from around the world design and test ultra-energy-efficient vehicles. The event also sparks debate on future mobility challenges and inspires young engineers to push the boundaries of fuel efficiency. Another example is “European Association of Geoscientists and Engineers (EAGE) Challenge” where multi-disciplinary teams of student are invited to characterise a real hydrocarbon field provided by a world-recognised oil & gas company and propose most economic development strategies. This event takes place every year during the annual EAGE Conference & Exhibition.

A similar competition could be organised with the help of professional bodies. The competition could either be themed around a subject area of interests (e.g. reservoir modelling, EOR applications, shale gas recovery) or be an open challenge that industry can support through their expert professionals or use of old datasets.

Additionally, most bachelor’s courses offer a sandwich degree where a student can take a year out to work within the industry and achieve vital experience. This can help prepare graduates for the industry and provide hands on experience. Provision of advanced laboratory set-ups is also crucial for successfully delivering the next generation of petroleum engineers. Advanced computer labs with all the latest industry standard software packages allows faculty to integrate them into the course through assessment or demonstrations. Additionally, software packages contribute a great deal to research and innovations. Also, visualisation of field equipment (e.g. Drilling Pipe, Bit, Logging Tools, Production tools) enhance the learning experience of the students. Though doing all they can, universities find it difficult to purchase all the equipment they would like. In such cases the industry can definitely contribute a great deal and enhance the learning experience of the students by donating used equipment that can be displayed in university laboratories.

Providing students with access to field sites will help them visualize the operation and interact with field professionals. Such interaction brings them to the reality of production

technology and elevates their learning experience. There is a general belief that no industry can survive unless it succeeds in inspiring future generations to join its ranks.

CONCLUSIONS & RECOMMENDATIONS

Petroleum Engineering is an important area of study that requires innovative and collaborated effort from both industry and academia to ensure that the best practices are taught and also students are able to maximise their learning in order to be highly employable in this high technology industry. New teaching methodologies which promotes creativity, independent thinking and problem solving should be part of the curriculum that enhances the skills of student. Collaboration is key to the success of Petroleum Engineering especially between the academia and industry where investment is needed to promote tailored courses that would suit the needs of the industry. Utilising internship opportunities for young faculty members and students to give field experience would go a long way in promoting relationships that could be useful for solving the industry problems in the near future.

To be able to address the current challenges faced by both academia and industry in promoting petroleum engineering as well as ensuring students are well equipped to take on the challenges within this sector, several considerations would have to be made among which are

- Courses should be taught in a way that relates units to each other and emphasizes their relevance to practical applications.
- Find ways that make students more proactive and engaged in learning and arriving at desired results on their own, we need to stop spoon feeding knowledge and information.
- Effort should be made towards the goal of attracting more and better prepared students to PE.
- Sharing field data and thus allowing more realistic examples and field cases to be presented to students, to enhance quality of PE courses, and better prepare the students for the oil business environment.
- Without compromising traditional science education, regarded as fundamental for engineering students, emphasis should also be placed on a broad range of information related to the oil business and the global economy. Be aware of risk, ethics, health, safety and environment.
- Establishment of channels, allowing free communication between Industry and Academia, must be a priority in order to achieve efficient and up to date courses.

- Industry feedback is important and certainly PE education for the next 20 years will be closely related to the future reserved to the industry.
- Align industry funded graduate research with the immediate needs of the industry, leading to close collaboration with the industry and the service sector.
- Establish a university-industry R&D conference, promote private one-on-one industry-university dialogue, and continue with the conventional university consortia

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Paper 4: A Holistic Analysis of the Impacts of Industry 4.0 to Engineering Education: From Concepts to Implementation

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KEY WORDS: Industry 4.0, Education 4.0, Internet-of-Things (IoT), Smart and learning factory, virtual learning environment, learning analytics

ABSTRACT

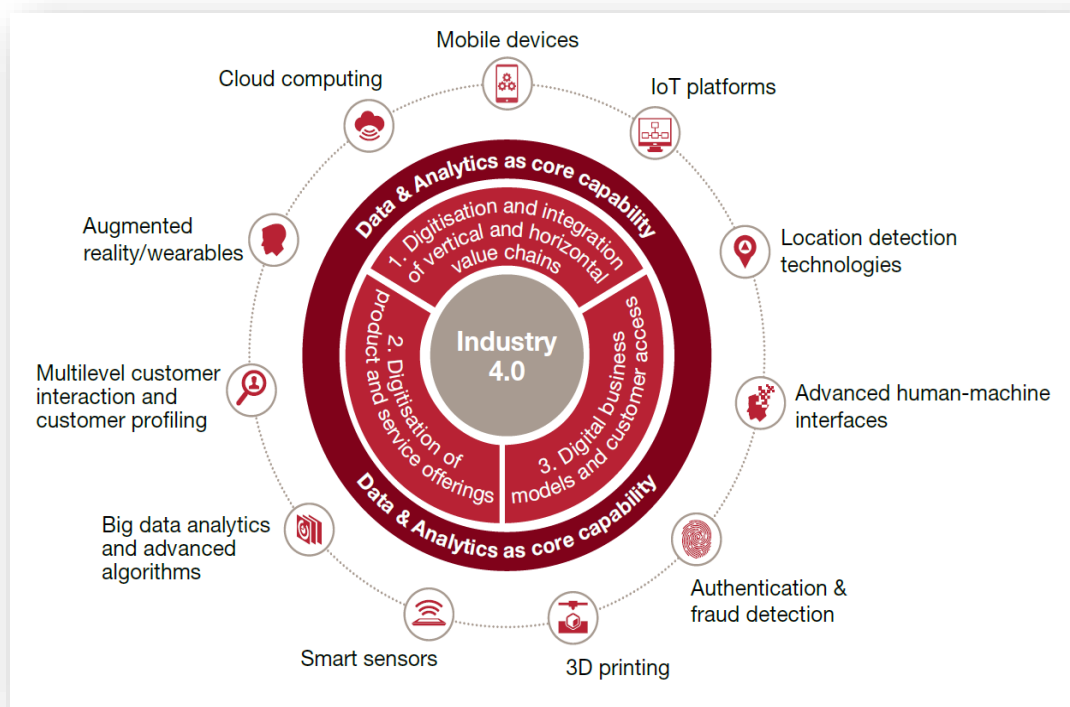
This research work-in-progress deals with a holistic analysis of the impacts of Industry 4.0 (I4.0) for engineering education especially for University undergraduate (level 4-6), master (level 7) and PhD related manufacturing, automotive engineering and supply chain management programmes. This analysis aims at providing support for further consolidated recommendations to enable the development of higher education engineering curriculum for enhancing I4.0 application for smart organisations and industrial companies within the digital supply chains. Also the paper provides an analysis of advancement from digitalisation in engineering education to the implementation of Education 4.0 and related practices for smart labs, and simulation of smart factories leading at the learning factory. A conceptual framework to support the application of big data and learning analytics in the School of Engineering from University of Wales Trinity St Davids, Swansea has been identified and intended to apply in the context of applying learning analytics.

INTRODUCTION

The Industry 4.0 has been initially called Industrie 4.0 as it was launch during the Hannover Fair in 2011; “furthermore, it was officially announced in 2013 as a German strategic initiative to take a pioneering role in industries which are currently revolutionising the manufacturing sector” (Xu, Xu and Li, 2018:2941). The industry 4.0 has included several technologies as presented in figure 1. Several recent approaches demonstrate how Industry 4.0 represents the evolution of the Fourth Industrial Revolution, upon which Information and Communication Technologies (ICT) form the infrastructural foundation for tomorrow’s

innovative industrial technologies and educational environments (Mourtzis et al., 2018; Xu, Xu and Li, 2018). The related roadmap presenting the main technologies supporting the evolution from Industry 1.0 to Industry 4.0 is presented in figure 3. (TSB Forum, 2015; Santos et al., 2017). This technological framework could be used for industrial engineering and management applications facilitated by the digital engineering education systems, tools and virtual learning environments.

Figure 1. Industry 4.0 Framework



Education 4.0 is a development based on Industry 4.0 applied concepts and digitalisation of higher education institutions and of teaching and learning practices. Advancement of digital and/or online education supported by an Education 4.0 framework will facilitate the development of skills and building graduates' competences for contemporary industry based on I4.0. According to Mourtzis et al. (2018) technologies such as Internet of Things (IoT), cloud computing, augmented and virtual reality, big data and learning analytics have an important role in engineering and management education, supporting advanced life-long training of the skilled workforce. It has been demonstrated that learning analytics provides insights about the teaching practices that could be rapidly adapted (Sclater, Peasgood, and Mullan, 2016).

The paper is organised in distinctive but inter-related sections that are addressing curriculum development to support Industry 4 leading to students and graduates competencies for future rapid employment. Other sections are dedicated to demonstrate the benefits of the application of learning analytics in higher education institution as a

complex organisation. Education 4.0 represents the application of Industry 4.0 framework and the associated technologies in education based on the intensive digitalisation.

RATIONALE AND LITERATURE REVIEW

The First Industrial Revolution has began at the end of the eighteenth century and early nineteenth century, which was represented by the introduction of mechanical manufacturing systems utilising water and steam power. The Second Industrial Revolution started in the late nineteenth century, symbolised by mass production using of the electrical energy. The Third Industrial Revolution began in the middle of twentieth century and introduced automation and microelectronic technology into manufacturing. These advances in manufacturing technologies were closely related to ICT. In the Third Industrial Revolution, the advancement of ICT was at the core of every major shift of the manufacturing paradigm. For example, the widespread adoption of computer numerical control (CNC) and industrial robots made flexible manufacturing systems (FMSs) possible; the technologies for computer-aided design (CAD), computer-aided manufacturing (CAM) and computer-aided processing planning (CAPP) made computer integrated manufacturing (CIM) possible (Feng, Li, and Cen 2001; Xu, Xu and Li, 2018).

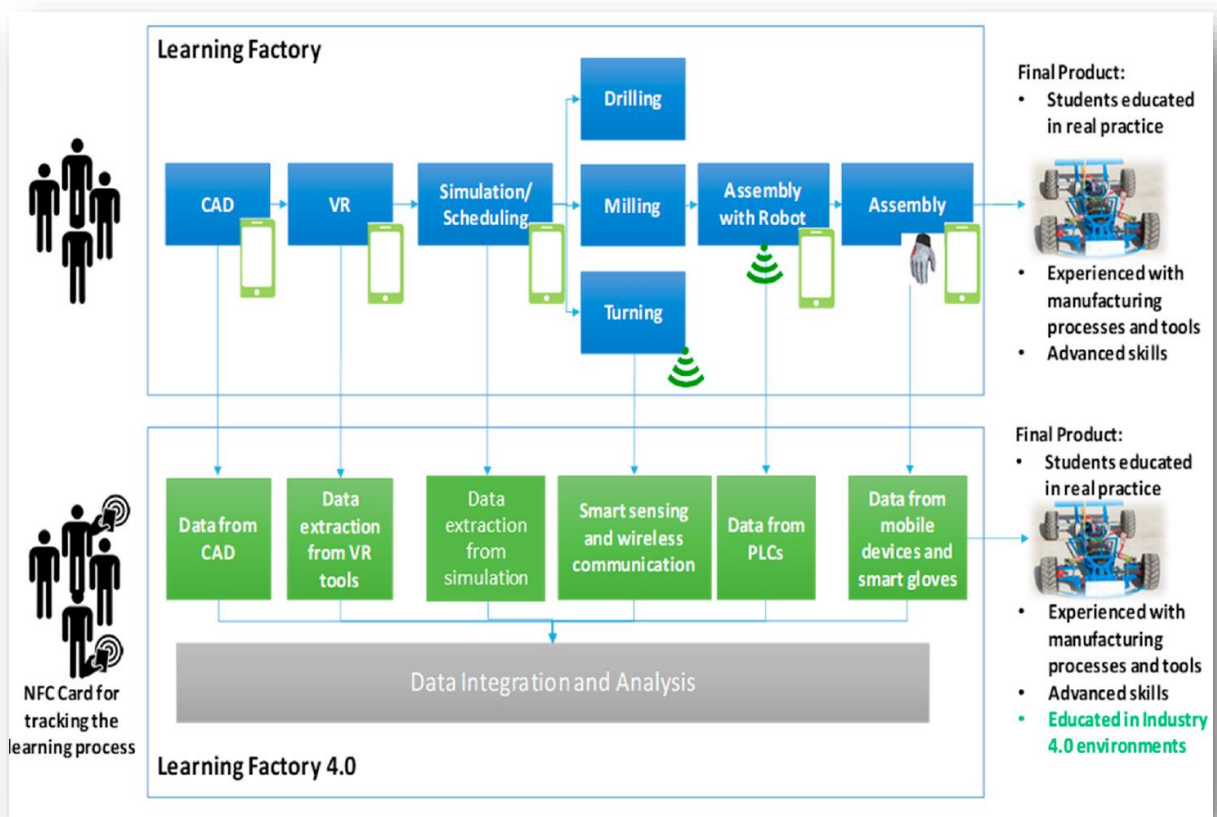
Industry 4.0 will change the landscape of industry related the following critical aspects (Santos et al., 2017) 1) Improvements in resource efficiency and sustainability of industrial systems, 2) Distributed and responsive industrial systems 3) human-oriented interfaces and improved work conditions. 4) Development of educational competences based approach and skills. Industry 4.0 aims to increase the digitalization of industrial companies and supply chains, facilitating the communications between people, machines and products, thus enabling real time access to product, production and supply chain information for participating entities, and the performance of autonomous work processes along the value chains. Thereupon, the European manufacturing sector expects to achieve a growth from 15% to 20% by 2030 if it fully implements the digitization of their value chains (TSP Forum, 2015). Also according to Santos et al. (2017) the digitalization of supply chain applying I4.0 can bring positive benefits for sales and operations planning of manufacturers, such as reducing the time to respond to unforeseen events affecting orders (around 300% improvement), to deliver orders (around 120% improvements) and time-to-market (approximately 70% improvement).

Some of the technologies associated with Industry 4.0 are as follows:

- Computer-Aided Design and Manufacturing (CAD/CAM) that support the development of projects and work plans for product and manufacturing based on computerized systems;
- Integrated engineering and logistics systems that support systems for information exchange in product development and manufacturing;

- Digital automation with sensors that are based on automation systems with embedded sensor technology for monitoring through data collection and analysis;
- Flexible manufacturing lines defined as digital automation with sensor technology in manufacturing processes (e.g. radio frequency identification (RFID) in product components and raw material);
- Simulations and analysis of virtual models based on Finite Elements Methods, Computational Fluid Dynamics, etc. for engineering projects and commissioning model-based design of systems, where synthesized models simulates properties of the implemented the model in real world;
- Big data collection and analysis that correlate of large amount of data for applications using predictive analytics, data mining, statistical analysis and others;
- Digital Product Service Systems incorporating of digital services in products based on IoT platforms, embedded sensors, processors, and software enabling new capabilities
- Additive manufacturing, fast prototyping or 3D printing;
- Cloud services for products and services.

Figure 2. Implementation of Learning Factory 4.0



The engineering education should take these opportunities and quickly respond to the challenges of educating the new generation of engineers and logistics professionals.

Therefore fundamentals of I4.0 and the associated technologies must be taught within the Universities and new curriculum should be developed and applied for new programmes and apprenticeships. Applying Education 4.0 in Engineering Education leads to learning factory 4.0 as shown in figure 2 (Mourtzis et al., 2018).

Extending this approach and the conceptual framework will contribute to the advancement of the traditional teaching to learning using Factory 4.0, integrating Cyber- Physical Systems and Industry 4.0 technologies and applying the Education 4.0 framework.

MAIN AIM & RESEARCH QUESTIONS

The main aim of this research is to contribute at accelerating the development of Education 4.0 based on a holistic analysis of the impacts of I4.0 and existing Engineering Education strategies and practices regarding digitalisation and generation of large amounts of data.

The research questions (RQs) are as follows:

RQ1. What is the current state of the art of the application of I4.0 in engineering education leading at Engineering Education 4.0?

RQ2. What are the benefits of applying Industry 4.0 (I4.0) for Engineering and Logistics Higher Education Programmes including apprenticeships?

RQ3. What transferable skills and competencies should be needed by the future engineers and logistics professionals to effectively work within an I4.0 industrial environment and related digital supply chains?

RQ4. What are the opportunities and challenges to embed learning analytics within Education 4.0 in higher education organisations?

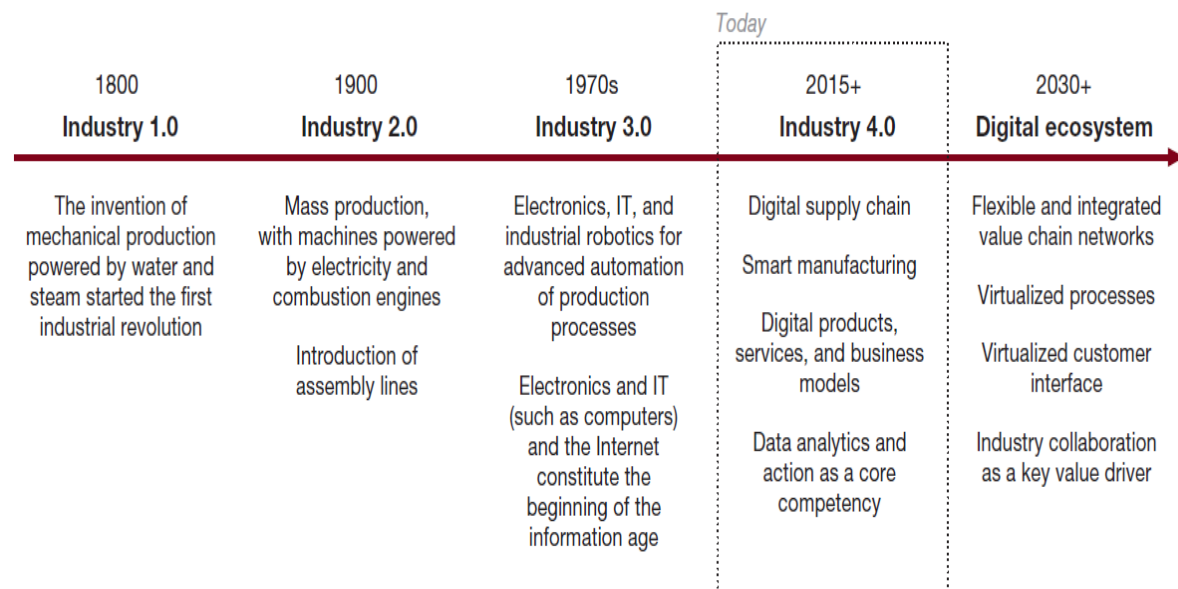
METHODOLOGICAL APPROACH

The methodological approach includes performing a systematic review of the literature and using content and thematic analysis (Saunders, Lewis and Thornhill, 2012). The work in progress is based on secondary data analysis of text presented in academic publications and reports.

Applying the research case studies (Yin, 2003) methods is based on success of application of learning analytics in higher education in UK Universities (Sclater, Peasgood and Mullan, 2016). This approach could lead to an action research that is a methodology that has become increasingly popular and has been developed in education, specifically at universities and schools directed to influence the best practices. Road mapping could be also applied in order to anticipate the future of the engineering education correlated with

industrial needs and skills requirements based on an existing roadmap for I4.0 presented in figure 3 (Santos et al., 2017)

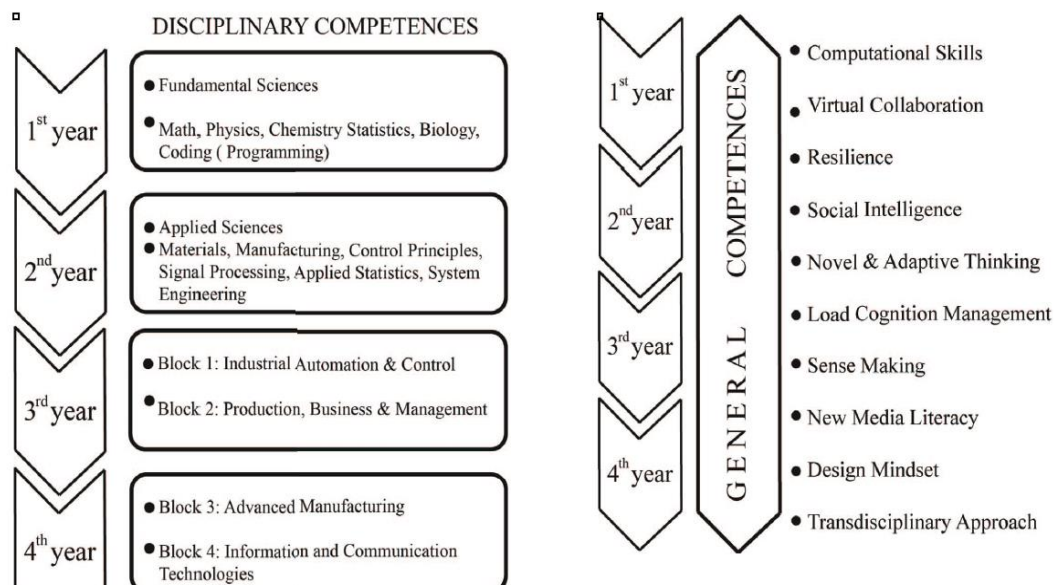
Figure 3. Roadmap of Industry 4.0



PRELIMINARY OUTCOMES

Competencies based education framework

Figure 4. From Knowledge and Skills to Competenceies

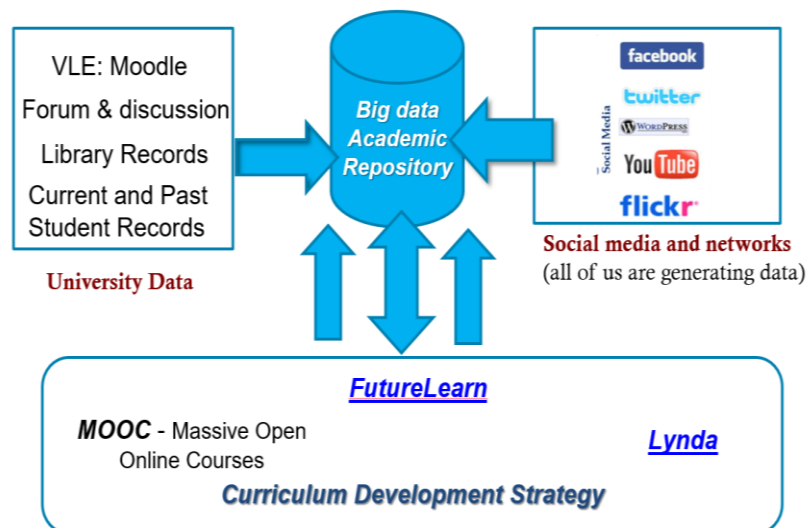


A comparative analysis of the current competencies, knowledge and skills and those required in the future is provided. Ramirez-Mendoza et al. (2018) have proposed the transition from developing skills and acquiring knowledge to competences based education that are presented in figure 4.

It is also anticipated that final outcomes of the research and the related models will positively influence the collaboration and engagement with industry in the School of Engineering from University of Wales Trinity St David (UWTSD), Swansea, United Kingdom. The Welsh Government addresses the economic development; transport; infrastructure; employment; skills; and research and development, including technology and science providing a set of recommendation as a result of emergence of Industry 4.0 in Wales (National Assembly for Wales Economy, Infrastructure and Skills Committee, 2018).

For a society and economy that enhance the development of 21st century skills in lifelong learning based on digitalisation of higher education supported by Education 4.0. 21st century skills encompass not only technical/engineering and domain-specific knowledge and expertise, but also domain-independent meta-skills such as critical thinking, creativity, communication, and cross cultural collaboration, and moreover dealing with the complexity of future industrial issues of Industry 4.0.

Figure 5. Conceptual Framework for Learning Analytics



Application of learning analytics

The outcomes include the definition of the current state of the art of I4.0 and Education 4.0 leading to recommendations to support the I4.0 and increase the benefits of application in

industry addressing the shortcomings such as interoperability, information transparency, and trust. The preliminary outcome is the conceptual framework presented in figure 5.

Based on the students' activities, their performance can be predicted applying data, text and web mining techniques (Berman, 2013) such as

- Regression
- Association Rules Discovery
- Classification
- Clustering
- Content and thematic analysis, and
- Running data mining software systems (RapidMiner, XLMiner, Data R)

Predictive Analytics enable prediction of student's behaviour, skills and performance by analysing various traces of their activities while actively interacting with the Virtual Learning Environment and/or using social media.

- **Learning analytics (LA)** is concerned with the collection, analysis, evaluation and reporting of data about learners and teachers aiming at understanding and optimising learning process, and the related supporting environments in which learning is performing (Daniel, 2015; Sin and Muthu, 2015).
- **LA** supporting the following aspects and issues in higher education:
 - Development and introduction of adaptive learning strategy;
 - New pedagogical approaches and development leading at redefining and applying learning styles (Kolb, 1984)
 - Quality assurance and improvement;
 - Student retention; and
 - Overall student experience and engagement.
- **Academic Analytics (AA)** are related to the application of the business intelligence and practices in Higher Education Institutions. Business intelligence is a category of applications and technologies for gathering, storing, analysing, and providing access to data to support organisations to make better business decision (Chatti et al., 2012; West, 2012)

The main challenges of the application of big data and learning analytics are as follows:

- Data integration architecture and systems;
- Selection of suitable data processing, analysing systems and tools;

- Data privacy, especially the new data protection act, and ethical issues of using/exploring student and staff data.

The recommendations for implementing learning analytics are as follows:

- Selection of a suitable LA solution and systems
- Integration of VLE (i.e. Moodle) with other systems (attendance monitoring, feedback tracker, etc.) and related data bases
- Distinguishing between LA and AA that are oriented towards supporting administrative procedures in higher education institutions
- Moodle Learning Analytics (i.e. [SmartKlass™](#)) should be included as a component of the Moodle VLE to empower teachers/lecturers to manage the learning journeys of their learners.
- Institutional implication and agreements considering specific policies and regulations

Extending this conceptual framework will further support the implementation of Education 4.0 that is characterised by teachers and trainers using Industry 4.0 technologies (i.e. IoT, RFID) to involve the aspiring engineers and long life learners in real world simulations that increase the perception of the studied material. Additionally, teaching factories 4.0 will serve as an introduction for the aspiring engineers to the newly developed and implemented technologies, through hands on training and workshops that call the participants to utilize these technologies as a mean that will improve the quality and the effectiveness of their tasks, potentially unlocking new capabilities. The implementation of these technologies in the teaching laboratories will also boost their integration in a real industrial environment as the new engineers that have familiarized themselves with the true potential and the capabilities provided by I4.0.

CONCLUSIONS & RECOMMENDATIONS

The increasingly digitalisation offers great opportunities for Industry 4.0 and the generation of new teaching and learning possibilities in the higher education institutions. This has enabled to move forward rapidly as a global society in many respects, but has also led us to complex, diverse and interdisciplinary challenges that affect all areas of knowledge In order to meet major challenges.

The concept of I4.0 together with Education 4.0 bring significant innovation for industry, schools and universities. In order to adequately and timely respond to the need of equipping students with suitable qualification, skills and competencies the education institutions should adapt and the effects of the related changes will be significant, and required to be carefully developed and implemented. The current significant issues of qualified people, made changes in engineering education that will be an important step in raising the standard of engineering education programmes also adopting Education 4.0.

Therefore engineering education should develop and address the following aspects:

- Interdisciplinary educational programmes holistically teaching science, engineering and business courses / modules also providing rapid / real-time innovation of the programmes, and modules in partnerships with industry.
- Adaptive learning environment and associated strategies of rapid adoption.

The recommendations should be based on the interaction between industry experts, academics, and managers in higher education and IT developers of virtual learning environments.

From the technological perspective of I4.0 the following features should be addressed:

- Interoperability of the systems that represents the ability of machines, devices, sensors and people to connect and communicate among each other and on the Internet of things (IoT), as well as on other internet (global) connections and environments.
- Informational transparency and connectivity that is the features of information systems to create virtual copies of the physical world (various simplified, clear models) by connecting large databases and various sensor systems.
- Information trust and relevance that are crucial for information sharing and exchange.

FURTHER WORK

The development and adoption of Industry 4.0 and Education 4.0 require further research, and practical applications and the main issues are briefly presented below:

- Developing a comprehensive framework for Engineering Education 4.0 in the School of Engineering from UWTSD.
- Engagement with relevant industry and research institutes in UK and abroad in the context of Industry 4.0 as well as with logistics professional communities in Wales leading to increase impact and collaboration.
- Analysis of the challenges and opportunities of applying the I4.0 for the whole logistics chains.
- Identification of the required competencies of future logistics professionals as well as the identification of the existing gaps in the educational programmes and in the related curriculum in the School of Engineering from UWTSD.
- Definition of the requirements for a new curriculum for Industry 4.0 applying Education 4.0 to logistics and apprenticeships programmes in the School of Engineering from UWTSD.
- Comparatively analysis the research and practices in the higher education institutions in different countries such as UK, Ireland versus Canada.

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Paper 5: Students as Partners in the Design and Practice of Engineering Education:
Understanding and Enabling Development
of Intellectual Abilities

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KEY WORDS: engineering education; student engagement; curriculum development; pedagogy; action research

ABSTRACT

This paper reports action research exploring the problem of engaging students as true collaborators in the design of a new engineering curriculum, with a focus on the development of intellectual abilities. Intellectual abilities – to deploy knowledge in analysis, create solutions, and exercise judgement – represent the essence of engineering, but cannot be directly taught. As educators, we must create learning experiences and an environment conducive to their development, by allowing students to integrate their knowledge, understanding and skills. Responding to this task requires us to understand, in detail, how students experience learning as young engineers, and answering that question was the starting point for the present work. We needed to engage students in our development process. Having found few tools in the extant literature to help us with the process of engaging students as partners, we present here alternative tools we developed with the dual aims of: (1) uncovering how students integrate their learning; and (2) engaging students as true collaborators in learning design. Findings are grouped into two areas: the first concerns the kinds of collaboration processes that are most amenable to achieving real insight into how students integrate and mobilise their learning; and the second group presents what we have uncovered about what contemporary engineering students are looking for in their education.

INTRODUCTION

Effective engineering practice relies on the integration of knowledge and understanding of engineering science, with practical and interpersonal skills to solve problems. The integration of these skills results in intellectual abilities – to deploy knowledge in analysis, create solutions, and exercise judgement – which are the essence of engineering, yet they cannot be taught directly. Instead, we aim to create learning environments rich in opportunities for students to make sense of and integrate the wide range of knowledge and skills gained throughout their degree programmes, and so to build their intellectual abilities and become graduate engineers. However, in spite of the efforts of engineering educators in this regard, industry continues to report that many graduates lack the capability to translate quickly and efficiently their degree studies into industrial contexts and to put their expertise to work in solving real problems (Royal Academy of Engineering 2007). Moreover, we continue to see calls for more applied, authentic learning environments (Royal Academy of Engineering 2010).

We report here our initial approaches to exploring this problem, focusing on our attempts to meaningfully work alongside students in the process. Our starting point was the beginning of a curriculum review, where we sought to understand students' experiences of studying on our programmes, initially through a focus group. We quickly needed to move beyond this passive consultation, realising that to foster the development of intellectual abilities, we first need to understand what it is like to learn in our programmes. We recognised that teaching staff are experts in pedagogy and course design, but are not experts in being students in 2018; we therefore needed close collaboration with students to bring that expertise to the table.

We describe and exemplify the techniques we have developed and trialled to build and foster true collaboration with students as partners in learning design, after unsuccessfully searching for such tools in the student engagement literature. We show examples of our students designing learning materials for their younger peers, so deepening and testing their own knowledge; discuss our students' development and operation of iForge, our student-led makerspace; and describe a process of having students design a module as a means of uncovering their thinking about what makes useful learning experiences, when students found this difficult to articulate directly.

Ultimately, we reveal how, using a variety of approaches has enabled us to observe the choices students make in their learning, and discover the kinds of activities that capture

their imagination in a learning and teaching context. We gained insight into the challenges they face as they begin their journey to become professional engineers. Importantly, we recognised and witnessed the real capability of students to have in-depth conversations about learning and teaching: they are able to make decisions in that context, when we provide a space for them to do this on their own terms, rather than through the pedagogical frameworks we use as educators.

BACKGROUND

Our initial exploration of the student engagement literature revealed that it is chaotic and difficult to navigate. As a relatively new area of work, conventional nomenclature has not been established, and even the term ‘student engagement’ is used with inconsistent meaning and scope. Sherry Arnstein’s 1969 ‘Ladder of Citizen Participation’ originated in her analysis of public participation in urban planning and has since been adapted to multiple contexts include student engagement. Bovill & Bulley (2011) apply different forms of student engagement to Arnstein’s ladder (Figure 1), progressing from tokenistic modes of involvement, where academics maintain control represented in the lower rungs, to more ambitious transfers of power in the top rungs, with students making substantive decisions.

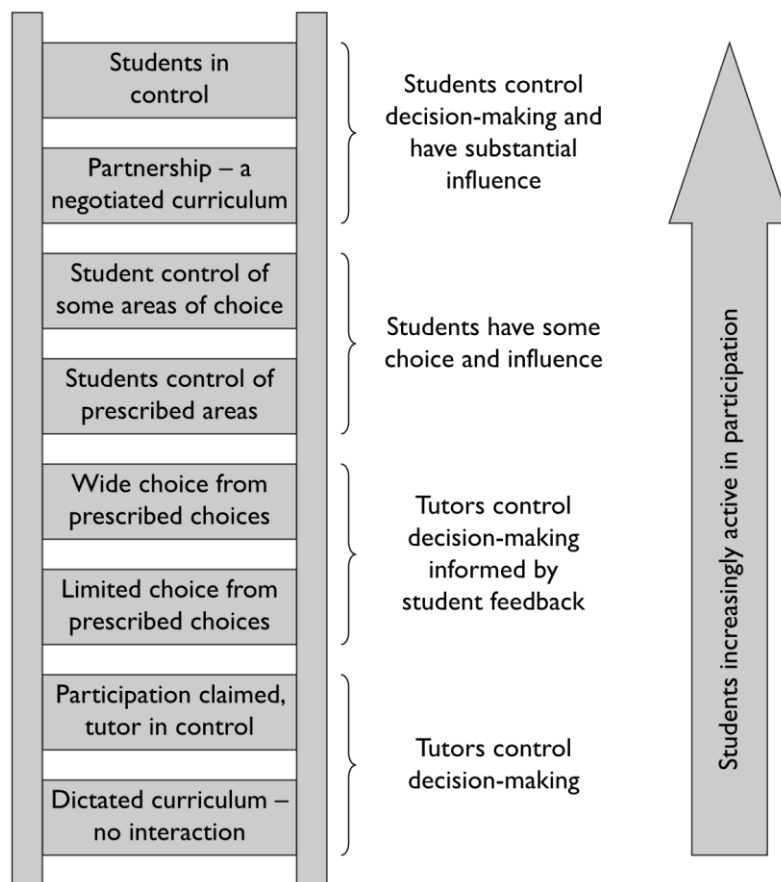
It can be argued that the accessibility of Arnstein’s ladder has been a function of its diagrammatic form and the relative simplicity that comes about with a focus on power as the single discriminator between the rungs. This poses some challenges in a context of uncertain meanings under significant pressure from external change. The curriculum is not an agreed upon set of facts, where the only question is who owns the decision-making responsibility. We argue that engineering curricula, under review in a dynamic HE environment and seeking to serve a fast-evolving industrial sector, necessitate deeper questions about what the purpose of HE is, and how students, academics and employers perceive and manage their roles within that purpose. At its simplest, we are highly skeptical that the ultimate objective of students involved in engagement activity is to control the curriculum they will follow, nor do we accept that students characterise their relationships with academics purely in terms of relative power. Consequently, the single penultimate rung of the ‘negotiated curriculum’ offers a limited basis from which to pursue these complex topics.

‘Jumping off’ Arnstein’s ladder, Collins & Ison (2006) move away from engagement characterised by power, towards engagement that is more attuned to social learning. They

note that a ladder exists to connect two points, so the metaphor is severely limited when it is lacking context:

In situations when the nature of the issue is highly contested or undefined, Arnstein's ladder provides few insights into how participation might be progressed as a collective process between all of the stakeholders involved.

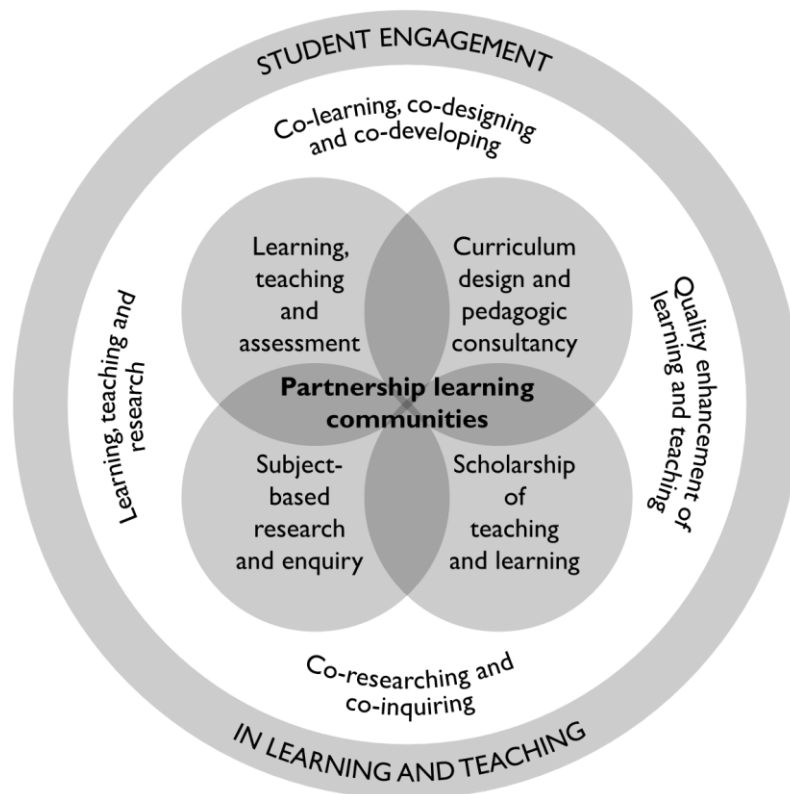
**Figure 1: Ladder of student participation in curriculum design
(adapted from Bovill & Bulley, 2011)**



Whilst it has not been applied to higher education, this work directly addresses processes of engagement in complex environments with contested understandings. The social learning lens brings new findings into view, which offer promise in understanding student engagement: a convergence of goals, criteria and knowledge; the co-creation of knowledge with transformative potential; and the behavioural change that emerges from social learning itself.

Healey, Flint & Harrington (2014: 15), provide a further useful overview of extant work on student engagement, recognising two broad areas of focus: (1) the way students invest time and energy in their own learning; and (2) the ways students can be involved and empowered by institutions in shaping their learning experiences. They further subdivide these two groups, using a conceptual model with four intersecting areas where students can be engaged (Figure 2): (i) learning, teaching and assessment; (ii) subject-based research and enquiry; (iii) scholarship of teaching and learning; and (iv) curriculum design and pedagogical consultancy.

Figure 2: Four areas of student engagement in learning and teaching
(adapted from Healey, Flint & Harrington, 2014)



Our interest in student engagement is in curriculum design and pedagogic consultancy. Healey, Flint & Harrington's review highlights that there are few examples of this kind of activity in the literature; it is the least developed of the four areas of student engagement that they describe. They note that:

Students are commonly engaged in course evaluations and in departmental staff-student committees, but it is rarer for institutions to go beyond the student voice and engage students as partners in designing the curriculum and

giving pedagogic advice and consultancy. Yet where institutions have implemented such initiatives, they have seen significant benefits for both students and staff. (p. 9).

Dunne and Zandstra (2011) observe a subtle but crucial difference between institutions who listen and respond to students, and institutions who allow students to explore and make recommendations about learning and teaching issues that are of importance to them. At a time of change in the UK Higher Education landscape, where there has been much pushback from academic staff and institutions against the idea of students as consumers, these authors make the important point that:

The concept of 'listening to the student voice' – implicitly if not deliberately – supports the perspective of student as 'consumer', whereas 'students as change agents' explicitly supports a view of the student as 'active collaborator' and 'co-producer', with the potential for transformation.' (p. 4)

A limited number of examples of students undertaking curriculum design do exist. For instance, McMaster University offers an Applied Curriculum Design module for third- and fourth-year science students, who design learning activities for first year students (Goff 2014, cited in Healey, Flint & Harrington, 2014). Oxford Brookes University's ePioneer Partnerships involves staff and students working as partners to develop digital literacy skills (Jisc 2013). At the University of Sheffield, we operate an institution-wide programme called Student Ambassadors for Learning and Teaching, where small teams of students complete projects to enhance the learning experience (University of Sheffield, 2018). Other examples come from the University of Lincoln's Student as Producer Programme, and Bryn Mawr College, where students act as pedagogical consultants to academic staff in their Students as Learners and Teachers scheme (Healey, Flint & Harrington, 2014). Perhaps the closest example to our own work comes from Uppsala University, where the Centre for Sustainable Development has students design and commission courses that are then taught by a team of interdisciplinary lecturers (Hald 2011).

What is notable about all of these examples is that they do not involve students working on the systematic design of the curriculum for their own degree programme, and do not attempt to engage students in activity that is itself revealing of the way that they learn, build knowledge within, and conceptualise their discipline. Both of these observations stand in contrast to our own approach reported in this paper. Moreover, projects reported in the extant literature involve students working together with staff supervisors and staff

guidance, rather than – as we have done – having students join curriculum design teams as equal members of the collaboration, and change agents in the process.

Before moving on to detail our research questions and process in more detail, it is important to note that tensions can arise in having students as true equals. As we have worked collaboratively with colleagues, and shared our approach more widely, a common reaction we have heard is that we as the educators are the experts, and we know best what students need. We generally have some pedagogical training – or, at least, experience – and we know more about the subject discipline than our students do. A common question, therefore arises: what value can students really add to the process? Our response to this question reflects Healey, Flint & Harrington's suggestion (2014: 14) that 'partnership embraces the different talents, perspectives and experiences that all parties bring'. Specifically, we acknowledge the expertise of academic colleagues in both a disciplinary and pedagogical sense, but we also observe that they lack expertise in being (engineering) students in 2018, taking their first steps in building engineering disciplinary knowledge, and developing the intellectual abilities required to put that knowledge to work skillfully in the ways that industry demands of our graduates. In contrast, our students are absorbed in that learning process right now; they understand and are experiencing what it is like to learn engineering today, and this means they have a perspective to bring to the curriculum design table that, without their engagement, we have no way to access. In short, building successful collaborations requires that we acknowledge that different collaborators bring different skills and knowledge to the task, and it is precisely because of that variety that the collaboration has value.

RESEARCH QUESTION

Our ultimate aim, in embarking on this work, was to develop an effective and inspiring engineering curriculum, informed by the needs of all stakeholders, including students. We want students to learn engineering science and maths, and to have the opportunity to integrate, make sense of, and leverage that knowledge as soon after learning it as possible. We believe that this approach supports students in establishing the relevance of underpinning science so they can engage with it more deeply, and develop intellectual abilities by bringing together their knowledge and skills to create solutions and value.

In order to achieve this aim, we needed to understand what it is like to be a student of mechanical engineering, and specifically a student in Sheffield studying mechanical

engineering, in 2018. As noted above, we recognised that to really access understanding of the student experience, we needed to engage students in our process in a meaningful way, for they are the experts in being students in the current environment; they understand what it is like to be engaging with engineering concepts for the first time and trying to make sense of them (for further discussion on the particular value students have in this process, see Cook-Sather, Bovill & Felten, 2014: 15).

An early challenge in our quest for an inspiring new curriculum that builds intellectual abilities was therefore to find ways to bring students' expertise into our curriculum team. It was this challenge that gave rise to the research reported in the present paper, which was guided by the following research question:

How do we work with students in a way that moves beyond ideas of 'feedback'?

To address this question, our starting point was our observation as practitioners that students need space and structure in their higher education experience to integrate the breadth of their learning and make sense of it – to see its relevance, and to make connections between concepts and tools. Educators cannot do this process for students, but we are charged with creating an environment that facilitates and encourages it. However, it is some considerable time since we ourselves undertook undergraduate engineering study, and many of us completed that in very different socio-cultural contexts and with quite different career aspirations. We therefore foreground a need to work collaboratively with current students to understand what it is like to learn in our programmes, where there are challenges and opportunities, and how students understand their transition into the workplace. The present project grew out of our finding that there were very few tools available to help us work with students that went beyond collecting feedback. Our approach has therefore been grounded in an action research methodology, and we have uncovered and developed ways of engaging students as we have gone along.

METHODOLOGICAL APPROACH

Action research is research carried out in the course of an occupation to improve the approach of the practitioner. Despite this relatively straightforward positioning, the methodology is adaptable enough to capture multiple personal, political and theoretical

perspectives, and the integration of these dimensions (Reason & Bradbury, 2008: 11). Practitioners of action research acknowledge a wide array of influences on their research including their own practice, their relationships with stakeholders, wider political contexts and their own personal relationships and role models (ibid: 16). Thus, it is a highly embedded methodology that aims to improve a given context. For teaching-focused academics, an action research methodology can effectively leverage and incorporate the student context we seek to understand, and reflects the responsibility we carry to contribute to new practice and learning.

This embeddedness brings with it methodological challenges. McNiff (2017) foregrounds the importance, in the course of action research, of continuously bringing one's motivations into the light for examination and challenge. This speaks to one of the main methodological concerns with action research: how does the researcher move beyond a reinforcement of a status quo in which they are immersed? In his seminal work on the development of the natural and social sciences, Jurgen Habermas (1971) drew attention to a number of motivations for research which he described as technical, practical, or emancipatory. Using these terms, we position this work as emancipatory: a concern with understanding the potential of our students, seeking to uncover questions as much as solutions.

Action research lends itself to many modes of data collection over what can be extended periods of time. The findings of this paper are based on a 3-year process focussing on three key points of intervention: (1) mentoring third-year MEng students through the process of designing an experiment for incoming first-year students; (2) introduction and launch of a student-led makerspace; and (3) having students returning from industrial placements design a new 150-hour module with sparse constraints and guidance.

The third-year design project (1) involved a group of five third-year mechanical engineering students. This was a semester-long, in-curriculum activity in 2017, and students had chosen this project from a list of around 30 alternative projects, most of which were industrially-focused. The student group was formally mentored by practical teaching-focussed academics throughout the process, and their approach captured through monthly reviews, the students' final design, and their report and presentation (Algar, *et al* 2018).

In the student-led makerspace (2), we worked with an initial cohort of seven students (rising to 24 throughout the process) from multiple levels, across different disciplines in the Faculty of Engineering. This was an extra-curricular activity, establishing a new ongoing operation with intensive mobilisation work happening over the course of four months in 2017, led by

student volunteers. The students worked alongside and were mentored by a teaching-focussed academic champion, who had seen makerspaces in practice. The student approach was recorded through observation and is seen codified in operational practice of the makerspace.

In the new module design (3) we worked with two final year MEng aerospace engineering students, who had completed industrial placement years immediately before their final year of study. This was a two-day extra-curricular activity in August 2017, for which students volunteered. Students were briefed by teaching-focussed academics, but worked independently to establish their parameters, process and outputs, and to consult a wider range of their student peers. The students' work was captured in the process documentation they produced.

Although each of these interventions had visible activity in 2017, it is important to the spirit of our approach, and the principles of our action research methodology, to see them as embedded within a longer-term process of reflection and relationship-building. These three activities do not lie as disembodied cases of practice. Instead, they were taken as opportunities to improve our pedagogical approach by enabling us to see, first-hand, how students go about sharing their knowledge and skills with other students. Through our observation, we learned how students understand their own educational experience, and the environment in which they learn.

The interventions have different outputs that are amenable to thematic analysis, and this is a valuable first step in starting to make sense of quite different experiences. However, the richer analysis comes in comparing and contrasting amongst these different interventions, using a grounded theory approach. Grounded theory is a methodology that puts aside existing theory, in favour of an exploratory approach to understanding a phenomenon, drawing on multiple analyses of data in order to uncover underlying patterns of interaction and meaning, and where data are analysed as soon as they are generated (Urquhart 2013: 4-5). Practically, grounded theory in this study was characterised by interventions analysed through an open coding process that identified concepts such as 'freedom', 'responsibility', 'usefulness'. These concepts were compared to other data sources that included focus groups with students and meetings with industrial advisers. This comparison served as a useful point of triangulation, to help with conceptual development in pursuit of theoretical saturation, a position where new findings are no longer emerging. At this point, clusters of theory can be built, which here were based on student prioritisation of autonomy, accountability and leadership, and authenticity in the education experience.

What was particularly helpful – but receives less attention in methodological literature – was the structured reflection through dialogue between the authors, and our colleagues (we acknowledge, in particular, the contribution of our colleague Pete Mylon). This was an extremely helpful way of understanding coding, clarifying our values and maintaining a currency and overview of our understandings at any one time. The ability to challenge one another on what we knew and when, what was and was not a reasonable inference to draw, and what the key concepts were, has proven invaluable given the day-to-day immersion in context that comes with an action research methodology.

KEY FINDINGS & DISCUSSION

Our first group of findings, from our work to date, relates to the kinds of collaboration processes that are most amenable to achieving real insight into how students integrate and mobilise their learning.

Our observation is that using existing learning processes as a basis of discussion brings about an over-emphasis on what Frederick Herzberg (1959) famously called ‘hygiene factors’, without actually reaching any deeper understanding of student learning (Gibbs & Wood 2019). Students are not equipped with a pedagogical understanding and lexicon that enables them to break free from the narrow framing of their recent experience, and the power dynamic does not support them to do so. Instead, we found that asking students to create and design ‘ideal’ learning experiences, with as few constraints as possible (for example, “what should we do with this 20-credit space?”), yields transformative results. Using these tools, students are able to express more freely the outcomes they want to achieve; our experience to date is that this is always couched in terms of capabilities rather than disembodied knowledge, and students naturally integrate across multiple learning outcome areas, in contrast to the way we traditionally conceive of modular courses.

We emphasise that the purpose of using activities such as designing ideal learning experiences is not to generate solutions directly, but to provide a space in which researchers can watch students at work, making visible the thought processes so often left invisible. We argue that this is where the real value of the process lies.

That said, the outcomes can have value, and this leads onto our second finding: that the outputs from collaborative processes are genuinely useful, leading to insights that would otherwise have remained hidden, and some of these are highlighted in the following section and implemented in curriculum change at our university. More unstructured ways of working with students have led to the very things that can be a barrier to working – naïvety and lack of specialist educational language – being one of the most valuable aspects of the interactions.

Our third finding is that staff-student collaboration can be very disorienting, and requires the development of particular capacities in academic staff, including: a genuine interest in the student perspective, and ability to navigate understanding before jumping to solutions; and the ability to understand and translate the *spirit* of students' aspirations to the more structured implementation environment in which we work. We believe these capacities go a long way to avoiding the tensions that the literature is keen to flag, and highlight a need for further work in this area, to better understand how to support and develop the capabilities of practitioners to effectively engage students.

Our second group of findings relates to what we have uncovered about what contemporary engineering students are looking for in their education.

The first aspect to highlight is the way students talk about agency within their learning. We have found that students talk about the freedom with which they can or cannot navigate the academic environment not through a lens of module choice (as valuable as that is), but in terms of access to expertise. In our research-intensive institution, students want to be able to draw on expertise in areas relevant to their own interests and aspirations, or be helped to make connections with industrial experts outside the organisation. They reflect an innate sense of the university being the hub of a rich environment, and want to be able to draw on that to follow their own interests and pursue their own interests.

Second, students consistently express a desire for tools, not just knowledge. This speaks directly to the difference between knowledge and understanding, and intellectual ability. Students want to be able to solve problems and develop tools they can carry into the future. This is true across the curriculum: scientifically; in software; and in management decision-making.

Our final finding relates to the topic of educational preferences and the importance of authenticity in assessment. As students look to develop more value in their education – and particularly when students have applied their skills and knowledge in a workplace through time in industry – they are attuned to the difference between ‘real-world’ and that which is ‘jumping through hoops’. Constraining students to knowledge-based or skills activities, when they want to be integrating these to develop intellectual abilities and the consequent accomplishments, is a very frustrating experience for them.

CONCLUSION & RECOMMENDATIONS

The main significance of this work as it currently stands is for engineering educators and HE leaders. It reveals that meaningful student engagement, especially in curriculum design, is a viable and worthy aim in the process of change and development. The work starts to attend to a literature gap in curriculum design and pedagogical consultancy which is recognised but lacks examples (Healey, Flint & Harrington, 2014).

The prevalent pedagogical model for engineering education – where engineering science and maths are seen to provide the foundations of the curriculum and consequently occupy the majority of space – has continued for more than a generation (Dym et al 2006). It has prevailed despite long-term calls from employers for graduates who can apply knowledge to real-world problems (RAEng 2007); calls across the sector for more integrative, applied learning environments (RAEng 2010); and a transformation of the scale and diversity of the engineering undergraduate population in the United Kingdom.

We hope with this paper to stimulate reflection in the sector on what colleagues believe the culminating capabilities of the engineering curriculum to be, what they know about how students develop these abilities, and how they believe students are supported in this regard. We suggest that only by engaging with students can we see how they make meaning of parts of the curriculum, and in turn develop intellectual abilities that empower them as young engineers. We want to encourage our colleagues to be radical as they seek to understand their own context and cohorts. We believe the HE landscape has changed sufficiently to warrant a movement from limited ideas of ‘representation’ to collaboration, challenging ourselves to understand our students on their own terms, not using outdated models. As educationalist and philosopher Paulo Friere (1996) so famously said, ‘If the structure does not permit dialogue, the structure must be changed.’

DEDICATION

With much sadness, but great gratitude, we dedicate this paper, and the work it represents, to the memory of our graduate and collaborator, David Adam Minn. Despite being taken from our collaboration too soon, the enthusiasm and big warm smile he unfailingly brought to our work together – indeed, to life itself – continue to inspire us, and thus to benefit our students.

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Theme Summary: Outreach and Inclusion

The second largest theme with seven distinctive papers, Outreach and Inclusion represents something of a 'hot topic' in Engineering Education Research. The first paper in this section provides a summary of a systematic literature review undertaken as part of a PhD study about the challenges of attracting female students onto university level engineering programmes. Ken-Gaimi et al, University of Portsmouth, introduces a study which promises to make a distinctive contribution to knowledge in this area.

A paper by Lazar et al, University of Bristol, focus on the issues around designing engineering outreach activities, drawing attention to the importance of assuring all stakeholders work together to maximise the benefit of such activities. Interestingly, a wide-range of stakeholders are identified including schools, students, teachers, parents, universities and communities. The following paper then expands the outreach theme to include all STEM activities. Hill, University of Portsmouth provides an analysis of STEM outreach provision in the South East of Great Britain before going on to suggest that there is a need to focus more attention, in terms of STEM Outreach activities in schools, on under-represented and minority groups.

Evans & Minshall, University of Cambridge, continue with the outreach theme, looking at how getting involved in engineering outreach activities can promote employability amongst graduate level manufacturing students. This is followed by a paper by Broadbent, Aston University, who provides a more focused approach focusing on outreach Engineering Education Activities in Primary Schools. Arguing that insufficient space is given to children in primary schools to think about engineering, or even to reflect of engineering outreach activities they might get involved in, Broadbent argues that there is a need to conduct Engineering Education Research in this area.

An important contribution is made by Nortcliffe et al who discuss the 'engineering education pipeline' within the Kent & Medway areas. Primarily conducted to determine the potential engineering talent available to study Engineering on a new programme being developed at at Canterbury Christchurch University, this paper uses a range of analytical and GIS tools to provide evidence that the area has fewer students studying the pre-requisite 'A' level subjects of Maths, Physics and other Sciences than do other areas of the UK. Concluding by emphasising the need to introduce 'engineering habits of mind' to primary school children, this paper is important in that it highlights the dangers of not introducing children to engineering.

The final paper in this section is unique. Written as an essay Heywood, Trinity College Dublin provides a historical account of the 'A' level merry go round reflecting on his own experiences.

Paper 1: Paper Title: Making Engineering Attractive for Female Participants

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KEY WORDS: Engineering education, sustainability, gamification, Analytic Hierarchy Process (AHP)

ABSTRACT

The systematic literature review and statistical analysis studies which highlighted the under-representation of women in engineering have indicated a strong connection of the core three pillars of sustainability themes in attracting female participants to choose engineering education and professions. However, the relationships and impacts of the social, environment and economic aspects of sustainability (the three pillars) themes interdependently on female participants' decision to enter and remain in engineering are yet to be determined. A combined gamified web-based survey and Analytic Hierarchy Process (AHP) tool was designed to determine as well as to quantify their relationships. The tool can also be used to introduce the sustainability concept aiming to educate and attract females including those from the non-engineering backgrounds to choose or engage their studies and/or careers in engineering. Once the relationships are confirmed, the outcomes from the survey and AHP analysis, although not part of this report, can be utilised to determine and develop a logical and theoretical model for identifying the optimal three pillars combination that influences females to enrol and remain in engineering.

Being a female from a non-engineering background, the author's engagement and lessons learnt from the selection, adaptation, and implementation of gamified web-based survey and AHP tool could be seen as the opportunities for non-engineers, especially females, to become attracted and involved in the engineering fields. This reported work signposts the author's perspective and approaches to address the challenges of female underrepresentation in this field by the adaptation of an engineering research.

BACKGROUND

Albeit females have long been given access to non-traditional or male dominated sectors of the economy, there are still sectors with a gender balance problem, such as in STEM sectors especially engineering, in spite of its significance to the growth of societies [30, 43, 46].

According to the Women's Engineering Society (WES), only 9% of the UK engineering workforce is female with only 6% as registered engineers and technicians [30]. In 2014, only 1.7% of women were involved in the engineering construction sector. However, researchers have argued that female participation in this sector is critical to the economic growth of many countries, with a potential addition of \$28 trillion to annual GDP in 2025 [46]. There are studies that demonstrated a positive correlation between women in decisional positions and corporate financial (economic) performances [53, 22].

In addition to this problem of females' underrepresentation, the engineering industry still grapples with an acute scale of skills shortage, mostly felt in developing nations. UNESCO in 2010 reports that 2.5 million new engineers are needed in Africa to provide access to clean water and energy for 1.1 billion people having no access to clean water, 2 billion with no electricity supply and nearly one billion going hungry on a daily basis. Invariably, this underscores the dire need for more engineers to help in solving these increasing sustainability challenges [57]. Furthermore about 64% of the UK engineering employers have expressed a shortage of engineers which is a threat to their business, these businesses have argued that they are 15% more likely to perform better if they are gender diverse, yet WES data showed in 2010 that nearly 100,000 female STEM graduates from UK institutes were unemployed or economically inactive.

There have been lots of research and published reports that looked into overcoming this skills shortage problem in engineering. One of many solutions is to address the persistent underrepresentation problem by attracting more students, especially females' into studying engineering [30, 46]. Separately but almost concurrently, there are several studies indicating implicit connection between gender diversity and environment and social performances in addition to the previously mentioned economic performance which practically are the three aspects or pillars of sustainability [6, 20, 25, 37, 53]. There is however no known evidence or quantitative measure on the interdependency of these aspects in relation to their influence or impact on female participants' decision to choose, enrol and remain in engineering.

Therefore, one of the motivations of this research is to find ways of addressing the underrepresentation or gender balance problems in the engineering field by investigating the influences and impacts of the three sustainability aspects to attract female participants to choose and embark in engineering.

To achieve the aims, the research utilises a combined qualitative and quantitative (mixed) method, for example in the first stage, to perform the systematic literature review (SLR) and statistical analysis in order to determine factors that influence or not influence the decision of female participants to choose engineering studies or professions. The outcomes, which are briefly discussed in the following literature review section, reveal that 59% of the literature reviewed suggested that there were factors identified with strong relevance to sustainability themes. The web survey was designed to incorporate the Analytic Hierarchy Process (AHP) that allows for identifying the weight of these factors in influencing the decision to choose engineering and their connection to sustainability. With the AHP integration in the web survey construction, the research bias can also be tested or assessed.

This paper reports the implementation of AHP methods in the construction of the web survey as well as the gamification method. The gamification method involves developing a gamified web-based tool to introduce the sustainability concept and to improve the survey's participation, especially among the young adults. Although not currently within the scope of the paper, the web survey can be further developed to be an e-learning tool to introduce the concept of sustainability themes. With the built-in AHP tool, there is also the scope to determine the optimal combination of the three pillars of sustainability themes that can be used by academic institution/organisations/industries to strategize their focus and resources to attract and/or retain female participants in the engineering education and profession.

SYSTEMATIC LITERATURE REVIEW

There were descriptive studies that identified the motivation of female engineering students to choose engineering as their first degree [4, 41]. These studies underpinned the motivation to be closely related to the social impact of engineering such as 'to make a better world' or 'to serve people'. Engineering Professional Responsibility Assessment (EPRA) survey has been conducted to measure the attitudes of engineering students towards personal and professional social responsibility at five institutions. The study, which recorded a thousand valid responses, showed that female engineering students demonstrated more positive social responsibility attitudes than male students [7].

Also corroborating these studies, a Slovenia case study of STEM students future career priorities and the important factors that necessitated their choice of STEM degree, found that although all students were in favour of pursuing fulfilling and interesting careers, females were more interested in interpersonal career priorities like helping other people, contributing to the society and protecting the environment, than males [3, 11]. The study further showed females were more inspired by lessons in subjects with relevance to society, and as such, the most influential factor for their choice of study. This study also indicated

that classroom or subject learning would be one of the influential factors to motivate female participants to choose engineering.

Morgan et al have reported some of the reasons of career choices provided by female students [45]. The female participants were likely to follow career paths that are people oriented, many wanted to subscribe to care-giving as against status goals or to lead a socially responsible engineering career [8, 18, 28, 47]. This indicates the aspiration around the quality of life/support systems (family and community) can influent the decision to choose engineering.

In the relation to sustainability themes, Klotz et. al. produced a sustainability survey data study on the career outcome expectations (motivation) of students interested in civil engineering and other engineering disciplines, anchored on social cognitive theory [36]. They found that female civil engineering students are more perceptive to, and significantly more likely than their male peers to focus on addressing sustainability issues i.e. social aspects such as poverty, distribution of wealth and resources, and opportunities for women and minorities.

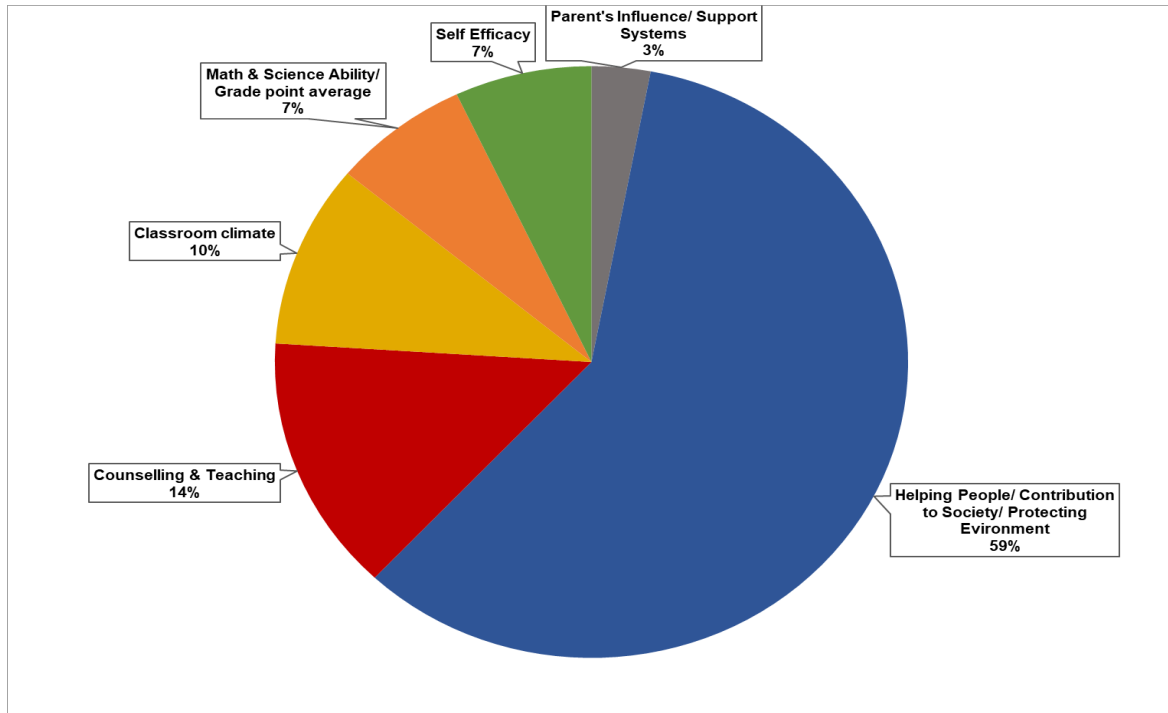
Corroborating this result, another study showed little similarity between male and female attitude toward sustainable engineering (SE) [42]. Although some studies have argued that the difference between females and males understanding and attraction to sustainability issues / engineering is barely noticeable and sometimes similar, this is however inconsistent with findings that recorded high percentages of women attraction to sustainability themes [24, 36].

There is a more recent research which focused on studying the relationship between gender diversity in corporate boards of companies and environmental sustainability [33]. Findings from this study revealed that both 'demographic' and 'structural' gender diversity are significant predictors of a firm's environmental sustainability initiatives. Galbreath [22] who revealed a positive link between women on boards and economic growth on the other hand could not prove the significant relationships between women on boards and environmental quality.

As previously mentioned, the first stage of the research was to perform the SLR and statistical analysis in order to determine factors that influence or not influence the decision of female participants to choose engineering studies or professions. From the systematic literature review conducted with over 100 published and peer reviewed conference and journal papers, 59% of these papers implicitly link sustainability to female participants' decision to study and choose engineering as professions. Many of these studies have so far,

focused on exploring the factors that motivate and attract more women to engineering. The results from some of these studies showed that women in STEM were largely attracted to themes with relevance to society and people impact. Figure 1 illustrates the findings.

Figure 1: Influential factors for females' choice of engineering



Simultaneously, statistical analysis on female participation in engineering in the UK and other selected countries has been performed. Figure 2 shows the female representation in four areas of professions in the selected countries. These data suggest that the percentage of female representation in engineering related professions is not affected by the size of the countries and therefore the number of populations such as USA vs. UK.

In line with the findings of these studies, results from the statistical data analysis conducted in this research showed a low participation of females' in STEM, with much lower participation, recorded in engineering & technology, as shown in Figure 3. The highest percentage of female participants was recorded in Biological Sciences and subjects allied to medicine.

Figure 2: A comparison of Female Participation in Different Professions across Selected Countries

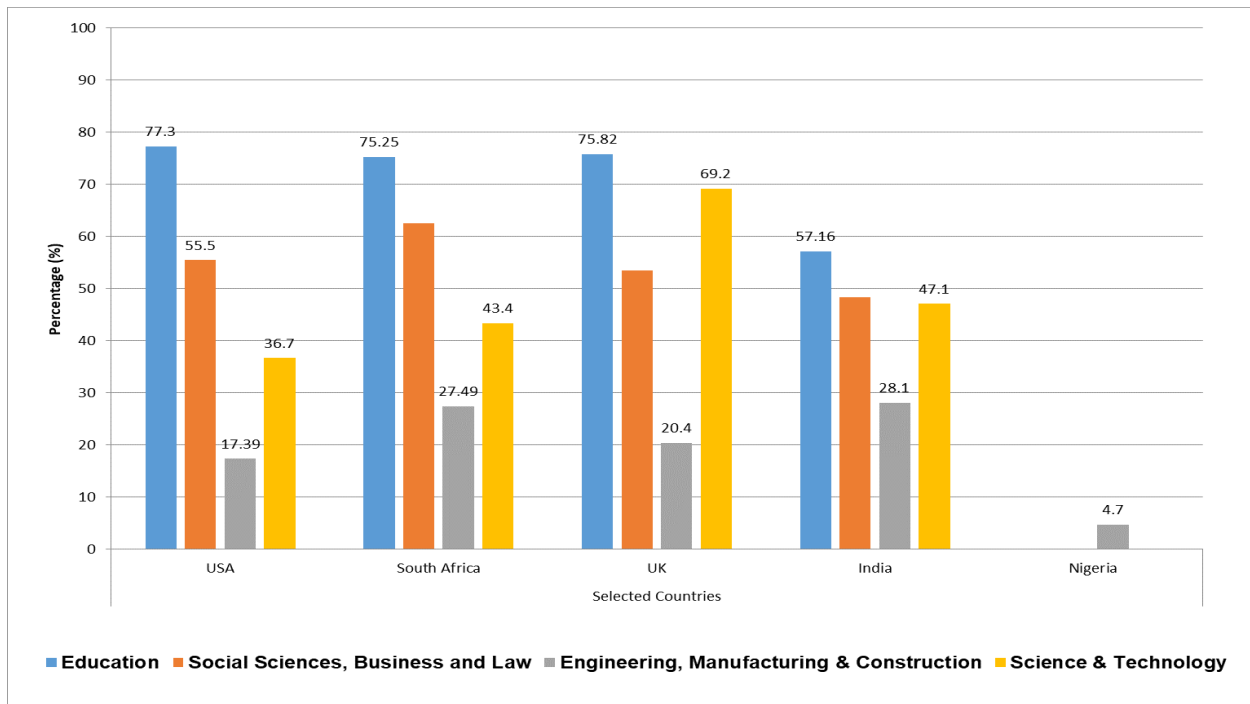
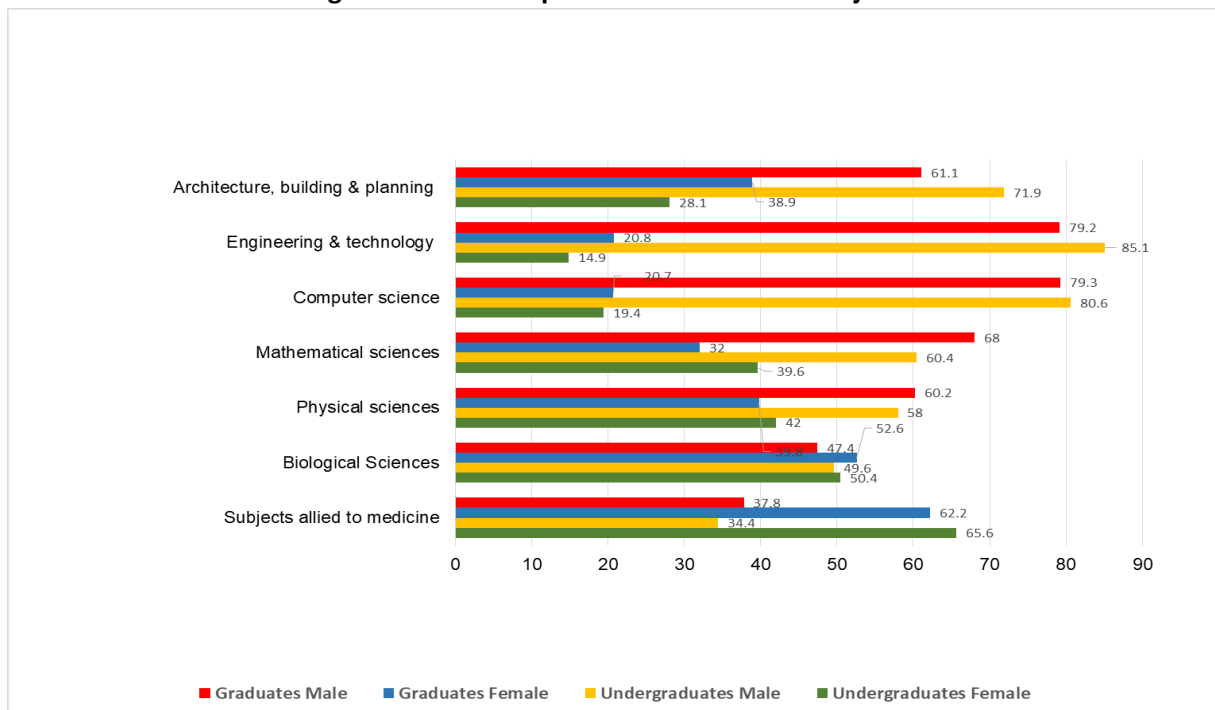


Figure 3: Gender representation in STEM Subjects



The findings also particularly revealed a higher proportion of female participants in Engineering and Technology at graduate level in comparison to the proportion recorded at undergraduate level, in Figure 4. However, a quite worrisome significant lower proportion of female professionals were recorded; indicating that a higher number of the few female

engineering and technology undergraduate/graduate students do not proceed to practice as professionals.

Figure 4: Trend of female participation in engineering

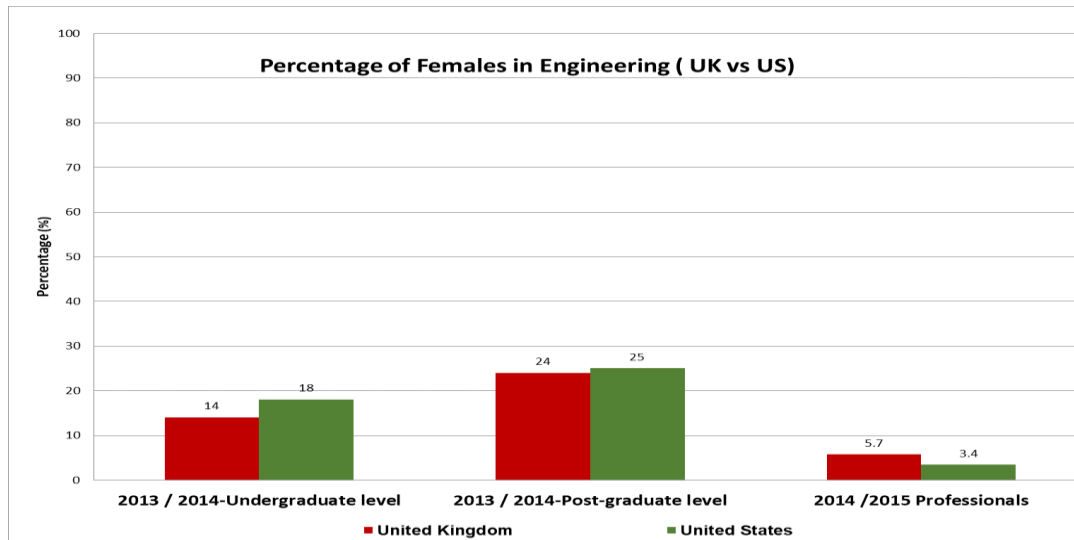
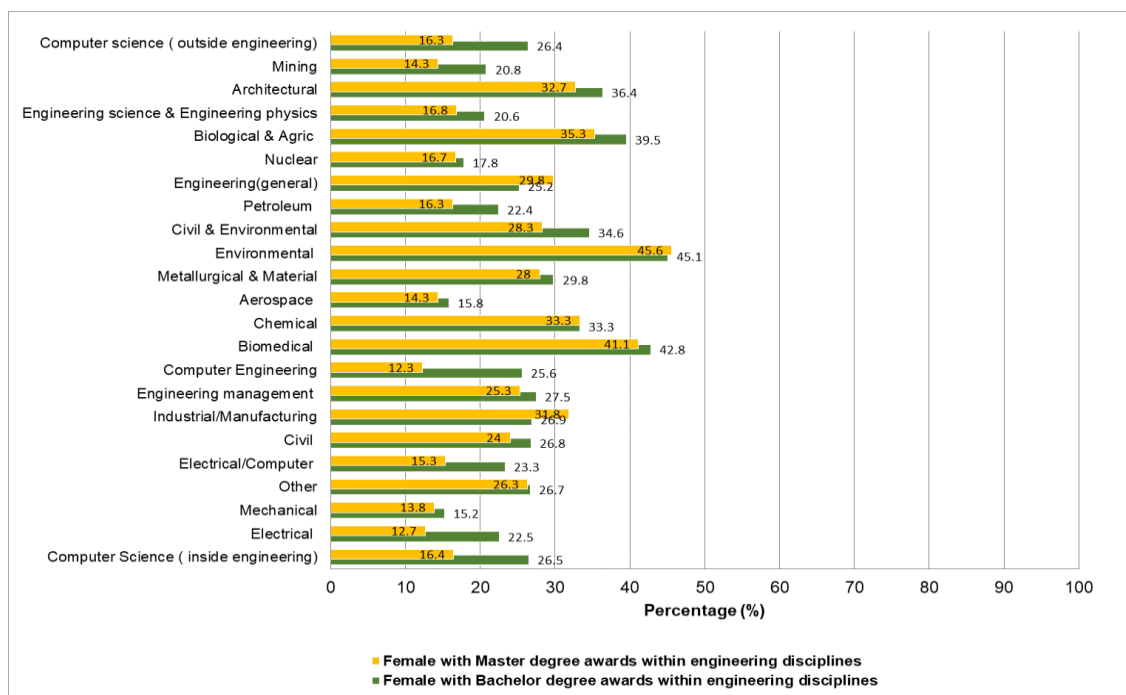


Figure 5: Proportion of female participation within engineering disciplines



Interestingly, the findings in Figure 5 indicated that despite the low proportion of female participants in engineering as a whole, a relatively higher proportion of female students were recorded in Environmental, Civil & Environmental, and Biomedical engineering disciplines. This could be indicative of the interest of female participants in engineering, as

well as the direction from which to explore the options of attracting and retaining them in the profession.

Despite these many studies, gender diversity in the engineering profession and its relation to sustainability continues to be elusive. One thing that can be concluded from these studies is that gender segregation still persists at overwhelming rates across male dominated sectors in Science, Technology, Engineering and Mathematics (STEM) as a whole, but more especially in engineering, which is renowned as the most gender segregated discipline amongst all STEM fields.

Therefore, building on females' interest in sustainability concepts seems to be an opportunity for the engineering profession to both advance on sustainability and gender diversity as supported by Stevens suggestion that the failure to advance on sustainable development may be linked to the same failure to advance on gender equality [52].

This opportunity, however, calls for significant efforts from engineering educators/institutions to showcase the connection between the concept of sustainability and engineering in order to attract more females. A study across European countries revealed the magnitude of this obligation. The results showed that although 78% of female students indicated that their attraction to sustainability themes was instrumental to their commitment in their career as engineers, they however do not see how both connect [56].

Invariably, this means that coupled with the rising trend of sustainability challenges and the dire need of engineers in the world; determining the key factors in line with the three aspects of sustainability that could increase the female attraction hence participation in engineering disciplines in order to drive an increase in gender diversity and sustainability practices in the profession, may well lead to both advancing on sustainable development and gender diversity in the engineering profession.

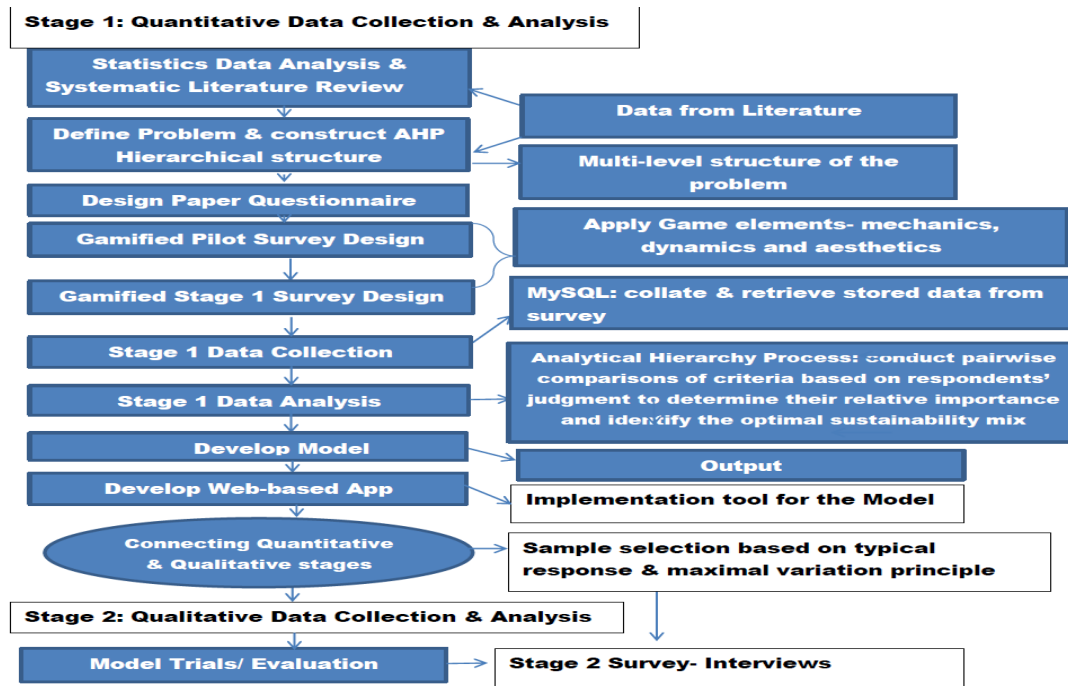
METHODOLOGICAL APPROACH

In this section, the main aspects of the methodology employed in the author's research, i.e. the gamified web-based survey and the AHP, are highlighted.

Figure 6 illustrates the use of a sequential explanatory mixed-methods design in this research, which incorporates both quantitative and qualitative data in two successive phases [1, 13, 14, 34]. This method is a type of the several mixed-methods research designs that is frequently applied in both social and behavioural sciences research [9, 31, 32, 34, 36].

The rationale for the use of a mixed-method research design is primarily to gain better insight and understanding of the research problem [14, 54]. This is owing to the fact that neither quantitative nor qualitative data alone is sufficient to submit a detailed explanation for a problem and therefore the use of both methods will maximize their strengths for a more robust analysis of the problem [23, 44].

Figure 6: Sequential Explanatory Mixed method



Therefore, following the steps in Figure 6, the research design will be divided into 2 stages as follows:

Stage 1: Quantitative

For stage 1, the research aims to conduct a survey in order to determine the link between females' interest in engineering and the three pillars of sustainability themes; in an attempt to identify the optimal combination of these themes that can drive/influence females' selection and retention in engineering.

The survey also aims to validate the results of the quantitative statistical data analysis and systematic literature review already conducted to determine the influential factors driving female participants' selection of engineering.

Sampling Approach

The process of selecting the sample required to carry out this research resulted in mapping out the target, potential and sample population.

The sample population size for each group of participants was calculated using Yamane's simplified formula [60] for calculating sample sizes as follows:

$$n = \frac{N}{1 + N(e)^2}$$

where n= sample size, N= population size, e= precision level/confidence interval, with a 95% confidence level and $\pm 5\%$ confidence interval/precision level.

Selection Criteria

Inclusion Criteria:

- Female engineering students were selected according to the type of institution and the region where the University is situated, first year and final year at undergraduate level as well as postgraduate level in Nigeria and the United Kingdom.
- School age female students (aged 15-18) in Portsmouth and nearby counties and Nigeria for the stage 1 survey.

Exclusion Criteria:

- Institutions without or less than two engineering disciplines.
- Institutions participating in the pilot survey
- Male students

Recruitment Strategy

- Invitation through emails and letters to school and university heads and organisations' contacts which will be determined from their websites or through personal contacts.
- Students' Facebook and WhatsApp groups
- Student contacts through Heads of Schools or Supervisors.

In addition, prior to stage 1, a pilot survey with a small sample of the selected population, will be conducted to understand how students interpret and answer the survey questions, to be used in refining the final survey instrument for Stage 1 of the design, in order to ensure validity and prevent misunderstanding and failure to complete by the students [21, 59].

The survey will adopt the format of a gamified questionnaire, to increase the participation of targeted young survey participants (students aged 15-18), optimize their understanding of the underlying concepts, whilst engaging and improving the user experience and data quality [27]. This gamification of web-based survey approach encompasses the use of game mechanics and elements in non-game context such as a survey [16] and has been selected as the means of quantitative data gathering.

Therefore, it proposes a more enjoyable and less boring experience for the research participants as it mitigates the criticisms that underlie online surveys such as reduced attention, speeding, untimely termination and random response from the participants, as a result of its traditional dull design.

Analytical Hierarchy Process (AHP) will be then be utilized to analyse the data generated from the survey [47] providing a logical and theoretical framework for identifying the optimal three pillars combination, which will be incorporated in the proposed model design.

The Integration of AHP Tool for Statistical Data Analysis will involve the following steps:

- Retrieve and collate data from survey responses using the MySQL database and Excel.
- Conduct pairwise comparisons by setting up a matrices of $n \times n$ elements, where n = no. of criteria/sub-criteria, using the AHP scale.
- Normalize the [C] matrix: divide each element in every column by its sum.
- Input normalized matrix on expert choice to derive the criteria [W] and the Consistency Index (CI).
- Conduct Sensitivity Analysis to consider the “What If” scenarios in order to verify the results/findings.
- Develop the proposed model and analyze its impact through interviews in the stage 2 part of the study.

Stage 2 – Qualitative

Stage 2 comprises the qualitative part of the research design and will involve the use of a multiple case study, presenting the web based app developed from the results of the Stage 1 quantitative design, to three institutions (one from each group of the sampled population: female school/college students, university students and professional engineers) selected from those who complete the Stage 1 survey [51, 61].

A case study is an exploration of a bounded system or a case over time through detailed, in-depth data collection involving multiple sources of information and rich in context [40]. A multiple case study design includes more than one case [61].

The use of case studies in Stage 2 will aid in explaining how and why the optimal three pillars of sustainability related themes, as examined in Stage 1, was significant and relevant in influencing the decision of potential female participants to choose, enrol and remain in engineering as well as provide an additional insight to the quantitative data collected from stage 1 study [61].

This qualitative part of the research design proposes a sample selection based on typical responses and maximal variation principle following the findings from the stage 1 study [32]. These typical responses from the stage 1 questionnaire will require further questioning to gain a deeper insight into the phenomenon being studied.

Therefore, examining the same population will allow for validation of the model developed in stage 1 through triangulation of the participants' responses [15]. The realization of the three pillars of sustainability model in a Web- based App format will also serve as a tool for engineering education/industries to reach out to female participants to make an informed decision in their choice of engineering as a career.

STRATEGIES ADOPTED & ANTICIPATED OUTCOME

Strategies Adopted

This section outlines the selection process, the adaptation of the gamification procedure and framework as illustrated in Figure 7 [26] as well as the approach taken to develop and integrate the AHP in the design of the gamified web-based survey.

Figure 7: Survey gamification process

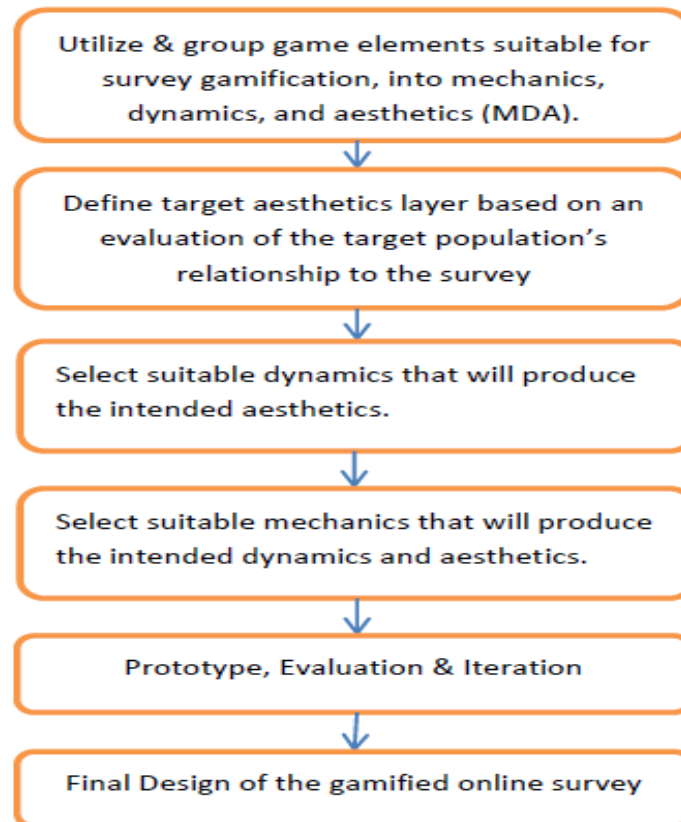


Figure 8: Game Elements Applied in Main Survey Areas

Application of Game Elements in Survey Areas

Survey Areas	Game Elements Utilized
Introduction/ Welcome screen	The mechanic of profile rank or trophy to produce the aesthetics of curiosity and acquisition of profile status from the start of the survey.
Questionnaire- Questions & Answers pages	Mechanic of avatars to produce the aesthetics of exploration.
	<p>Mechanic of completion badges to display the percentage of completion on each questionnaire page and to implement the target dynamic of feedback.</p> <p>Questioning Application of game-like techniques to questionnaire wording, i.e. projection & forced imaginary situation.</p>
Submission page	Mechanic of 100% completion achievement badge and profile rank or trophy .
Thank you page	A thank you message with a graphically designed sustainability profile rank and corresponding profile is shown to each user based on their responses.

The Gamification of Survey Approach

The gamification approach incorporates a unification and application of the MDA gamification framework (mechanics, dynamics and aesthetics) [29, 58] in the survey areas (Introduction/Welcome page, Questions & Answers, navigation and submission).

Following this gamification process utilised, game elements suitable for producing the target aesthetics and dynamics were selected to be applied to the key areas of the survey as shown in Figure 8.

Integration of AHP in Survey Design

Utilising the AHP in the design of the survey questionnaire afforded the benefit of breaking down the research problem into a multi-level hierarchical model of objectives, criteria, sub-criteria and alternatives.

Figure 9 shows the AHP model developed for this research, which is divided into 4 levels. The goal on level 1 is the focus of the problem; the criteria on level 2 are the elements (criteria) that contribute to the goal, i.e. the three aspects of sustainability themes that can significantly influence female participants' decision to enrol and remain in engineering. The sub criteria on level 3 represents tangible sustainability related issues that cut across the three aspects of sustainability, which will give us better insight into the diverse aspects of sustainability themes that can attract an increase in female participation as well as highlight the different opportunities and possibilities that a career in engineering can bring to prospective participants.

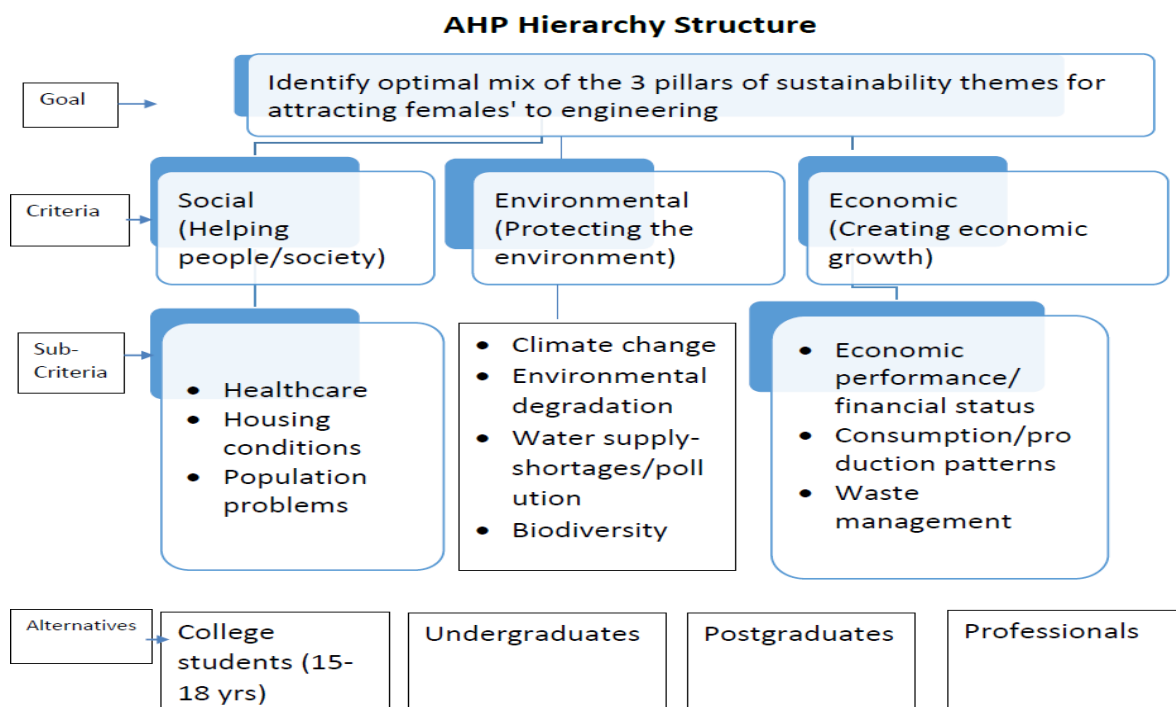
ANTICIPATED OUTCOME OF METHODOLOGICAL APPROACH

Employing game mechanics such as the dynamic of feedback systems or mechanics of badges and aesthetics of challenge or acquisition of status in the design of the survey, proposes the following outcomes:

- A significant amount of psychological and behavioural benefits as it relates to user experience, participation, motivation and quality of data [10, 17, 24].
- The propensity to reach more respondents than other survey methods.

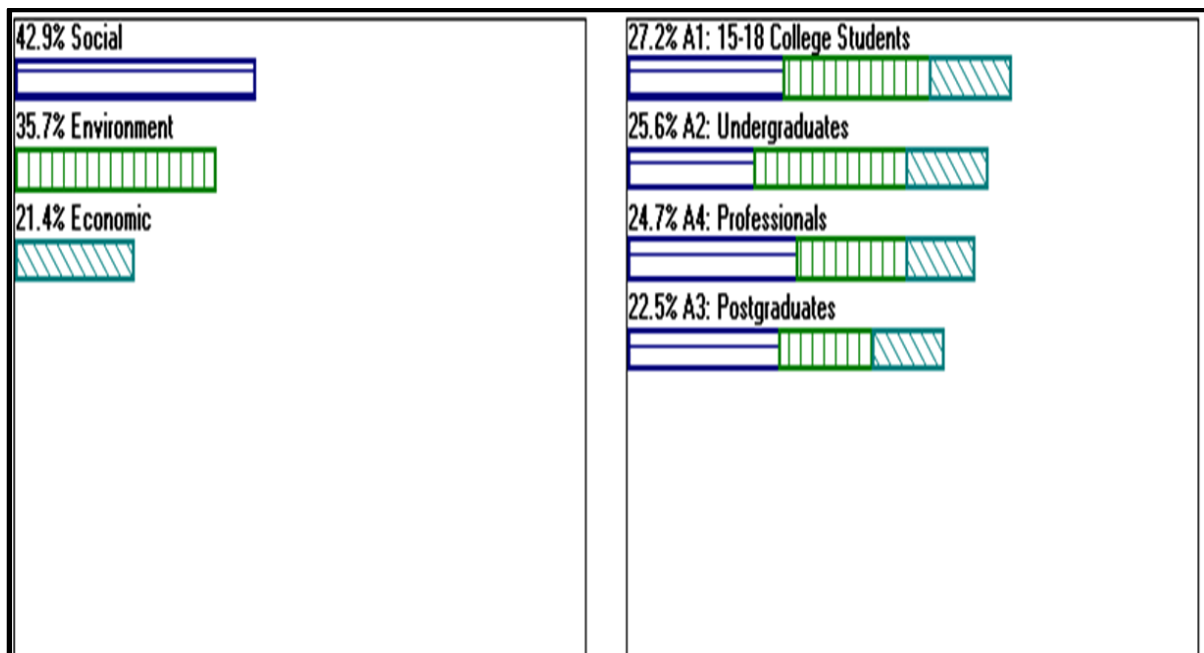
- Low Cost, making it easier to collect data repeatedly and severally from a larger number of participants [49].
- It allows for a faster and cheaper data analysis, from a direct storage and capturing of the data electronically [2].
- Possibility of High-level Interaction and Content update through the use of game elements [29].
- Ensure validity and prevent misunderstanding and failure to complete by the students [21, 59].

Figure 9: AHP Hierarchy Structure



Additionally, the implementation of the AHP tool in a survey design and analysis will determine the relative weight of certain options against a given criteria by conducting pairwise comparisons between the options [38, 47]. Therefore, adopting the AHP in this research, proposes to contribute to a better understanding on the degree of importance, placed by the different groups of female participants (which represent level 4 on the AHP model), on the selected options of sustainability themes (represented on level 2 and 3). The results of this analysis will identify the weights assigned by the different female groups on each criterion, that is, the three aspects of sustainability themes and the subthemes, which would lead to identifying the optimal combination to be incorporated in the model.

Figure 10: Sensitivity Analysis Graph Demo/Simulation



Furthermore, following the calculation of the criteria weights, a sensitivity analysis will be conducted by slightly modifying the input data, which are the criteria weights, in order to observe the impact on the results, that is the ranking on the alternatives, which represents the different preferences of the participants. If the ranking does not change, then the results will be said to be robust.

In this case as shown in Figure 10, if the sensitivity analysis gives this result with the criteria weighted this way, then it means that the majority of the female groups seem to prefer the social aspects of sustainability in relation to the two other aspects. Therefore, a series of 'what if scenarios will be conducted by way of a sensitivity analysis, by modifying the weightings of the other 2 aspects to observe for any difference in the preference of the different groups.

Therefore, the stage 2 stage of the research will be focused on understanding the reasons for the preferences of the different groups of female participants as well as any differences in the groups' preferences as a result of the changes in the criteria weightings during the sensitivity analysis.

DISCUSSION

A pool of research conducted to find out the possible ways of attracting and retaining females in the engineering field have suggested that an emphasis on sustainability subjects

and themes could play an important role in sustaining their increased participation in STEM and particularly in engineering. This engineering gamified web-based survey was therefore developed to not only introduce the sustainability concept but also to understand the link between gender diversity & sustainability. If such link were confirmed, this tool combined with the AHP could be further developed to determine the specific aspects and optimal combination of these themes that can optimally attract and retain female participants in engineering.

The survey is not just to gather data but can be utilized as an e-learning tool to educate female engineers and prospective engineers on the diverse options available in engineering careers, through the sustainability related themes in wider perspectives such as those 9 themes that are defined by Smalley's outline of ten most pressing challenges facing humanity [50] and the UN Commission on Sustainable development theme indicator framework [55]. Thereby making the survey instrument more interactive as well as rewarding.

Utilizing the AHP to understand the preferences of the different groups of participants, will not only help the researchers to determine the optimal combination of sustainability themes that will be incorporated in the proposed model, it can also help engineering educational institutions and industry to determine the different aspects of sustainability to focus on in their attempt to attract and retain a more diverse talent pool and possibly increase the profession's relevance in solving diverse sustainability issues prevalent in developing nations such as in Africa, particularly Nigeria.

One of the challenges perceived is on number of participants and data for a meaningful and useful analysis. However, by conducting objective quantitative analysis, including AHP in the methodologies, it would help the researcher to achieve the research aim.

CONCLUSIONS & RECOMMENDATIONS

Although links between female participation and sustainability aspects are yet to be verified and validated, results from the sensitivity analysis to be conducted in this research, could provide an insight to the robustness of the findings that showed the most preferred aspects of sustainability themes by the groups of female participants. This would lead to identifying the optimal combination that would be incorporated in the model as a tool to strategize and manage resources for attracting and retaining female participants in engineering.

From engineering education perspective, these findings could be used as a reference or an

indicator for curriculum teaching and learning development such as to include or reflect the less preferred sustainability themes in engineering topics and projects for a better understanding of the connection between these sustainability themes and engineering concepts, which could hence attract more female participants and thereby lead to developing a talent pool with a vast knowledge of the role of the 3 main aspects of sustainability to the engineering profession as well as the different opportunities available through these sustainability routes in engineering.

From a non-engineering background, the author's engagement and lessons learnt from the selection, adaptation, and implementation of gamified web-based survey and AHP tool is an indication of the opportunities available to non-engineers, especially females, to become attracted and involved in the engineering fields.

According to Matusovich, "To persist in earning an engineering degree, not every student must be motivated in the same way by the same things, and so there are many ways to reach students and help them connect to the personal possibilities an engineering degree could bring." [39]. From the author's opinion, the proposed approach in this research, could be recommended as one major way to motivate non-engineers, especially females and to achieve diversity in the engineering profession.

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Paper 2: Designing an Engineering Outreach Programme to maximise impact

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KEY WORDS: inspiration, motivation, interactive workshop, lecture, low participation areas.

ABSTRACT

This study looks into the design of outreach programmes meant to inspire young students to pursue a degree and a career in engineering. However, this does not reduce to reaching out to potential students only, it extends to including teachers, parents and the wider community in the conversation. Given the wide range of backgrounds and personal circumstances of the intended recipients of an outreach programme, we need to ensure we deliver diverse activities in diverse settings. This paper presents the activities offered by the School of Civil, Aerospace and Mechanical Engineering (CAME) at the University of Bristol, discussing our strategy, reach and impact, identified following initial evaluation. However, the question is what else could be done in terms of activities and other engagement opportunities and what resources are necessary (human and financial) in order to support a comprehensive outreach strategy. At the same time, evaluating the impact of such programmes presents many challenges, the impact being difficult to measure in many situations. Our findings confirm that it is very important to ensure that all stakeholders (students, schools, teachers, parents, universities, communities) work together to maximise the effectiveness of outreach activities/opportunities and that their collective efforts should lead to a slow, but necessary cultural change around education, which would benefit all fields, not only engineering.

INTRODUCTION and AIM

As a School, we run multiple types of outreach events and activities, some with a widening participation (WP) element. Although the two are not synonyms, everyday practice usually combines them. This is because, as an institution, we aim to offer new possibilities and perspectives to those who are unlikely to benefit from them in their everyday lives, for example students living or studying in deprived areas. In addition, there are other underrepresented categories, for example mature or female students, that we also want to cater for. The main goal of our outreach programme is to make them all aware of the possibilities that lie ahead such that, when time comes, they can make an informed decision for their future. To achieve this, we offer multiple types of activities, delivered in multiple

settings by academic staff or university students to audiences formed of pupils, parents, teachers or the wider community.

At the same time, we must acknowledge the importance of attracting more funding. Developing a successful programme which is thoroughly evaluated increases credibility, which helps this process. By attracting more funding, we manage to deliver more activities to a larger public, which will lead to increased long-term impact.

We acknowledge the fact that this is a work in progress paper and that an extensive review into the relevant literature is still to be conducted. The observations made are largely based on the reflections of the authors and feedback received from participants and colleagues.

CONTEXT

Public engagement, whether in the form of outreach, WP or a combination of the two, has become an increasingly important item on the higher education agenda. The Teaching Excellence Framework (TEF) states that higher education providers must clearly demonstrate their commitment to widening access and participation. In addition, funding bodies require that all grant applications demonstrate public engagement (for instance Pathway to Impact, EPSRC, 2018).

There are now grants dedicated to public engagement only, as the Ingenious award from the Royal Academy of Engineering ([Ingenious: public engagement awards - Royal Academy of Engineering](#), 2018). The University of Bristol included diversity and inclusivity in its strategy for 2017-2023 and is committed to making Bristol education more accessible to high-potential students in the local community (Vision and strategy - University of Bristol, 2017).

Bristol, as a city, is dealing with an education inequality crisis, where young students' participation in Higher Education is influenced by the area where they live. This was discussed at length by the City Council, the universities and schools in the area and also by policy makers, and we are all trying to concentrate our efforts on reversing this inequality and offering young people equal chances. Undoubtedly, running outreach activities in deprived areas and informing schools and communities about the possibilities ahead can help in this process.

At the same time, Engineering is facing numerous issues related to inclusion and diversity, ranging from bias to stereotyping and university programmes curricula that instead of bringing students together, seem to alienate those who are in minority (regardless of the criteria considered). The Royal Academy of Engineering published a report on 'Designing inclusion into engineering education', where institutions are helped in identifying where the problems are and also are given ideas on how inclusion could be embedded in the

curriculum ('Designing inclusion into engineering education' report, 2018). This is highly relevant because even if universities manage to recruit a diverse pool of students, they face retention problems, as students tend to leave the programmes if feel they cannot fit in. One way in which outreach can provide a solution here is by helping increase the number of students from less represented backgrounds, such that they do not feel isolated anymore. Another solution which we have successfully applied at Bristol is engaging undergraduate students in outreach activities such that they can inspire the communities they belong to and support younger pupils.

Several institutions have started embedding outreach into the undergraduate curriculum, which is highly beneficial because it engages students in outreach activities, thus supporting university staff. This also helps develop important transferable skills that may often be less prominent in STEM curricula (Aspinall et al, 2016).

At the same time, universities should get involved in these activities also because it is the right thing to do, because they have a duty to educate and a duty to care for the communities they are part of.

Given all the factors above, in our School it was decided that, although staff occasionally conducted outreach activities on an ad-hoc basis, organised summer schools and participated in wider University projects, having an in-house outreach team formed of academics would substantially increase our impact. Since the team's establishment in 2016, we have significantly increased the number of workshops we offer, we assisted academic staff with grant writing and we worked closely with the University WP team and other outreach teams. We strive to address all issues raised above and work towards enhancing our Outreach Programme to benefit our students and the community.

The following section describes the structure of our programme and presents the results obtained following the evaluation of selected activities. More details are provided in the discussion, before looking at possibilities for future work and concluding.

OUTREACH PROGRAMME STRUCTURE

This section shows the types of activities we run on an annual basis. We also look at the teams delivering a specific type of event and how this impacts the events. These events cover a wide range of audiences and settings, but we are always considering ways in which we could further diversify our offer.

Based on their duration, the outreach events we offer can be classified into:

1. One-session events (2h-3h): interactive workshops offered in schools, interactive workshops offered at the university, career talks, engineering taster lectures, panels.
2. One-day events (6h): invited thematic days to support school curriculum (delivered either in school or at the university), thematic days organised in collaboration with

industrial partners or professional institutions at the university, science and engineering fairs.

3. Several days events: work experience programme (5 days), engineering summer schools (ranging from 3 to 5 days), community-based events run weekly in deprived areas of Bristol.

If we look at target groups, we have:

1. Events dedicated to female students – fairs, open doors events, female-only outreach sessions, dedicated talks, dedicated summer schools.
2. Events dedicated to students in deprived areas – weekend STEM clubs run in collaboration with local community centres, charities or trusts, visits to and from target schools, widening participation programmes with a university entry route, dedicated summer schools.
3. Events dedicated to the wider public – fairs, panel discussion, open doors events.

Following every event, the university representative who led an activity is asked to fill out a feedback form. This form contains information on the activity itself, the resources used, the feedback received from the audience and recommendations for future activities. The data is mostly qualitative. In addition, for more complex events, we use forms to gauge the audience's feedback at the end of a programme. Since our outreach team was formed, we ran two cycles of activities and hence, more data needs to be collected before more conclusions can be drawn. This will lead to more rigorous studies being carried out in the future. Over the next subsections, we present two of our activities for which we have collected feedback data – the Innovate STEM club (weekly Saturday club run during term time) and the Work Experience Programme (run for one week every June/July). These activities were chosen because their format was designed by the authors of this paper and are fully resourced and delivered by our school. At the same time, they are different in nature, and we are hoping will offer a diverse insight into our work.

The Innovate STEM club

Many outreach activities tend to be single interventions which whilst may provide an opportunity to inspire participants however, this often leaves participants without viable avenues to explore any interest further. The Innovate STEM club looks to build relationships with participants and to provide continued engagement and opportunities to explore STEM and Higher Education (HE). This is achieved through the development of a community centre-based club in a ward with low participation and, at the same time, one of the 10% most deprived wards in England, Lockleaze.

This program started in 2016 and has been running and attracting new participants over the past two years. The STEM club is supported by our undergraduate and postgraduate students who supervise and assist participants in exploring engineering principles through building and programming Lego Mindstorm robots. This allows children to explore the

creative side of engineering, which can often easily be overlooked by the narrative of society, while also getting hands-on with Mechatronics. Through this programme, the School has also trained and developed 60 students as STEM Ambassadors who continue to participate in other WP activities through the STEM Network.

Whilst in-depth formal evaluation has yet to be conducted, we have received extremely positive feedback from the community, examples being “My daughter loved this club, rated it 10/10”, “My daughter keeps asking when the next Innovate is happening”, “my daughter loved going”. A more robust evaluation is planned for the next cycle and the outreach team is working on designing a coherent strategy to evaluate impact and implement potential feedback to further improve the club and our participants’ experience.

This project won a second-place community award for “Best Youth Project” in Lockleaze. As a result of this support from the community, the School is now supporting the development of another club in Southmead (another low participation area of Bristol) to provide further opportunities to those in areas of low participation in Bristol.

Work Experience Programme

The aim of this programme is to offer students an opportunity to spend a week at the university, working as researchers in Engineering. They have access to lecture rooms, laboratories and materials to support their learning. The students are also offered the chance to connect with academics and current students and learn more about life at university and the opportunities an academic degree offers.

This programme started in 2017 with a pilot offered to 10 students. Given its success, we received over 90 applications in 2018. We enrolled 30 students, 16 boys and 14 girls, from the Bristol area and beyond. The programme ran for 5 days, between 10am and 4pm. The first day consisted of an introduction of the programme, safety talks and introduction of the technical projects (half of the students focused Vibrations, the other half on Thermofluids). On days 2, 3, and 4, students worked on the hands-on project and the last day focused on showcasing their results. On the final day, we hosted a reception where we invited university staff and students, and the participants’ parents and schools’ representatives, in order to engage them all in the conversation and make them part of the students’ success.

For feedback and evaluation purposes, we created a reflective notebook that we shared with each student. They used this to record their learning and give us feedback at the end of each session. Examples of daily feedback are: ‘I can work with other people productively’, ‘if things go wrong it’s normal, just try and try again’, ‘we used our initiative to try and fix problems’, ‘I am now able to construct a sterling engine’, ‘[I learned] how to talk to people’, ‘[Now I know] how not to get angry at people [when things go wrong]’, ‘[I am] better at teamwork’. We also designed a questionnaire handed to students upon completion of the programme. The data is summarised in Table 1.

Table 1: Work Experience evaluation questions in 2018.

Question	Strongly agree	Agree	Disagree	Strongly disagree
I enjoyed my work experience	53%	37%	10%	-
I was satisfied with my work experience	47%	53%	-	-
As a result of my work experience:				
I better understand the skills employers are looking for	26%	68%	6%	-
I have developed some new skills that employers value	53%	37%	10%	-
I understand better why it is important to do well at school	47%	47%	6%	-
I understand better how workplaces are organised	31.6%	67.9%	0.05%	-
I am clearer about what I want to do in my future education and career	31.6%	58%	10.4%	-

In addition, we have received very good informal feedback from parents, as pupils shared their positive experience with them. At the same time, parents could see their children's work and are now more supportive of their aspirations, which could be very beneficial taking into account the known impact of parents with respect to pupils' career choices (Keller and Whiston, 2008, Palos and Drobot, 2010).

The staff and students delivering the work experience programme reported finding the experience very rewarding. They had a chance to discuss topics close to their specialties, and also to support students who are still in the process of deciding what degree to study and/or what career aspirations they would like to pursue.

In the next section, we discuss the variables that make a difference when doing outreach – who runs an event, how different types of events address different audiences and in what way do university staff and students benefit from participating.

DISCUSSION

All events/programmes organised by the School are run by academic staff, professional services staff, technical staff, doctoral students, undergraduate students or a combination of all three categories (we do not account for events run by students' societies, as we are not directly involved). While academic staff do occasionally run solo events, we would normally not allow undergraduate students to deliver an event without supervision. Experience has

shown that mixed teams work best, for instance an academic will be more knowledgeable and may engage pupils who challenge authority, but other pupils respond better to students, because they see them as peers, and feel more confident asking questions.

The place in which an event takes place also makes a difference in terms of impact. Having a school visit the university implies that in addition to running a hands-on workshop, there is a chance for pupils to go on guided tours and meet students from whom they can learn about university life. Going into a school or community can be more suitable when groups are large or when many institutions can organise activities at the same time. For older students, who are about to decide what degree they want to study, it is best to organise activities where career options are also discussed, or to offer them places on residential programmes that offer a taste of the university life and the examples can continue.

Another factor to discuss here is the impact of outreach activities on the staff and students who deliver them. Our staff and students reported these activities as being extremely rewarding. In addition, students gain valuable communication and presentation skills, that are very useful for their future career. The experience also makes them reflect on their own learning and feel more responsible. At the same time, professional services staff and technical staff, also valued the opportunity of interacting with students and delivering or helping deliver outreach activities. They are often not included in the conversation, although their roles are vital within any university. Moreover, potential students should be aware of the diversity of roles available in a university and learn about all available pathways. This supports the findings reported by Aspinall et al (2016) and by Clark et al (2016) among others.

The two activities presented in more details above, the Innovate STEM club and the Work Experience, owe part of their success to the factors above, that have been incorporated in the design and delivery process.

LIMITATIONS

As mentioned before, this is a practice paper, where we presented the outreach activities carried out by the School of Civil, Aerospace and Mechanical Engineering at the University of Bristol. At the moment, we are developing an impact evaluation framework aimed at assessing where future emphasis should be placed, to complement the activities /programmes we already run. A more in-depth literature review is to be carried out over the future months, to support the framework development and.

CONCLUSIONS

Following an analysis of the events organised and delivered, and of the feedback received, we conclude that it is beneficial for an Engineering School to have a dedicated outreach team that can develop a strategy and support other academics who want to get involved,

but don't have the time to do it on a regular basis. This setting also ensures that there is an opportunity for us to reflect on our practice and develop a coherent outreach plan.

It is also important to ensure that the outreach portfolio is diverse and can address a wide variety of participants, which we are doing by ensuring we deliver activities based in different settings and of different lengths, as presented in this practice paper.

Two flagship programmes were selected, the Innovate STEM club and the Work Experience Programme, to give insight into the structure and delivery of two of our most popular activities and the feedback collected so far.

Follow-up studies will be conducted when more data becomes available to analyse various types of activities in-depth.

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Paper 3: Identifying the landscape of university STEM outreach

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KEY WORDS: outreach; STEM; pipeline; recruitment; higher education

ABSTRACT

The UK is facing an engineering skills crisis; with problems in schools and colleges, like low attainment and progression in Science, Technology, Engineering and Maths (STEM) subjects, leaving the outlook as bleak. Claims are made in the 2016 Royal Academy of Engineers UK STEM education landscape report that there are gaps in outreach activities being offered by organisations, which if addressed could help increase the number of young people pursuing engineering. The report, although recognising universities offered these opportunities, did not include them in their mapping. This paper attempts to see if universities are possibly filling these gaps and if such provision affects recruitment in higher education, by examining what outreach activities a group of universities in Southern England are offering through their websites. By mining their websites and using content analysis, their provisions are evaluated against the suggested gaps identified in the report. The types and numbers of suggested activities are also compared against recruitment of students. Whilst the universities are closing some of the gaps, more progress is needed with others; including giving greater STEM support in Primary schools and supporting and encouraging underrepresented groups, such as those with disabilities, into STEM. With some strong correlations between outreach aimed at colleges and students enrolling on STEM courses, there is good reason to consider that addressing these gaps will also benefit universities recruitment into STEM courses in the long run.

INTRODUCTION

Science, Technology, Engineering and Maths (STEM) is a key issue in UK education at the moment, with decreasing numbers of students choosing to continue to follow STEM paths as they progress through the education system (The Gatsby Charitable Foundation, 2018). The reason we are seeing this leaky pipe model is widely discussed and various suggestions have been made how best to address it (e.g. Clark & Andrews, 2010; Tripney et al., 2010). For certain groups in particular STEM subjects, such as females in engineering, they are even less likely to progress to studying at a higher level (Institute of Physics, 2013). Whilst schools and colleges have a place to help address this, it isn't just a problem for them. Numerous bodies have a vested interest in ensuring there a high-quality stream of STEM skilled students available, from businesses to universities. To improve this many of them provide STEM outreach (enhancement and enrichment) activities, with the view that the students become more engaged in the subjects and inspired to progress further in their studies. The range of activities is diverse, in both type and audience. It can range from the STEM Learning (2019) Ambassadors scheme, where experienced professionals demonstrate and discuss their work with students, both in schools and colleges and through larger events like the Big Bang fair (2019), to universities developing longer term multidisciplinary projects to support teachers such as the University of Portsmouth's gSTEM programme (Hill and Mullhall, 2017) in primary schools.

The pipeline model isn't always seen as a helpful image, and the idea that engagement activities should act as a springboard that opens up higher possibilities across a wide range of options (Mendick, Berge and Danielsson, 2017). This is worth remembering when looking at developing more engineers. Engineering isn't itself part of the UK's National Curriculum, and so engineering courses are often filled with students who have studied other STEM subjects who are able to do so as engineering draws on knowledge from many other disciplines

RATIONALE

The Royal Academy of Engineers (RAEng) UK STEM education landscape report (Morgan, Kirby and Stamenkovic, 2016) mapped the provision of STEM outreach around the UK and from this identified gaps in the provision that could be affecting the flow of STEM students. Their mapping exercise chose not include universities though, although they did recognise there was provision of STEM outreach activities in schools and colleges by them. The

outcome of their report identified eight gaps in outreach provision, which they suggest may be limiting the number of people following an engineering pathway.

Whilst the term outreach in universities recently has been used interchangeably with Widening Participation (WP) – the duty of universities to encourage participation in higher education of students from groups who are identified by the Office for Students as being underrepresented and disadvantaged (Office for Students, 2018) – there is historically a wider interpretation around their civic roles and activities (Boyer, 1996). This has recently come back into the spotlight with the recent report by the UPP Foundation Civic University Commission (2019). As well as their civic responsibility to the wider education community, it is in the universities interests to ensure that students in schools and colleges remain engaged in the STEM subjects to create a larger pool of students considering following these subjects in higher education. A challenge they face in doing this, is to provide engaging and enthusing activities requires subject specific knowledge in their design and delivery. This usually falls to academics who have numerous pressures on their time, and outreach can be seen as a minor importance to their day to day work and often not seen as an effective use of time by senior managers (Johnson *et al.*, 2019). So, with the increasing pressures on universities to recruit (Hale and Viña, 2016), and fewer STEM students, there is a risk therefore they could see the shrinking, or possible closure, of their departments offering those courses. The importance and relevance of STEM outreach activities needs to be better understood more than ever.

The South-East Regional Engagement Consortium (SEREC), which is an informal biannual meeting of museums/science centres and academics involved in outreach from local universities, including: University of Bournemouth, University of Brighton, University of Chichester, University of Portsmouth, Southampton Solent University, University of Southampton, Sussex University and University of Winchester. SEREC allows the sharing of ideas and good practice in outreach activities, as well as to work collaboratively on larger projects. From these meetings it is possible to see that a wide range of activities take place, with some variations in focus and amount by each university. That it may be possible that some of the gaps identified in the RAEng report are being filled by the universities' activities. By identifying what activities are taking place and matching them against the gaps, it may be possible to highlight any areas of provision that are weaker than others. By virtue of examining this particular group of universities, the gaps about coordination of engagement activities has been ignored in this document.

As it's impossible to ignore the pressures on academics and the perceived value of outreach, we should also examine if there is a relationship between what is provided and the student enrolment at each university. Is there a direct benefit to the university, as well as that to society by having more students interested in following STEM pathways?

RESEARCH QUESTIONS

This led to asking two questions:

1. What is the landscape of STEM outreach provision being offered to schools and colleges by universities involved in the South-East Regional Engagement Consortium and do any of the areas highlighted through analysis meet the gaps in provision identified in RAEng (2016) report?
2. Are there any significant relationships between areas highlighted through the previous question and the students enrolled at those universities?

METHODOLOGY

Due to various constraints, this research had to be undertaken unobtrusively. As outreach activities are aimed externally, at schools and colleges, it requires communication in order to advertise or provide information about them. The best source of relevant and accessible data was therefore each universities' website. Websites offer the ability to reach a wide audience whilst being easily accessible, and are one of the first places teachers approach to find information about any outreach provision universities offer.

Netnography (Kozinets, 2015) is therefore used as the main methodological framework. This method draws from ethnographic research methods and studies forms of communication as independent research data. In the case of a netnography it focuses on internet communication data i.e. content of websites. This means that I make no suggestion that the website data I am investigating reflects underlying university activity. Studying the internet as a source of communication can examine the patterns and meanings in the forms of communication themselves (Kozinets, Dolbec and Earley, 2014). My methodology also shares elements of phenomenological research in that I focus on communication data, or appearances, as a research object in its own right (Langsdorf, 1994).

Thus. this research is being approached from a combined approach netnography/phenomenology (Husserl, 2012; Boos, 2017) constrained and limited by a critical-realist ontological perspective, that recognises that reality can be larger than our knowledge (Fleetwood, 2014). This means that, although the website data examined is important it does not assume that this data exhausts the underlying reality. The epistemology leans towards a pragmatic approach to netnographic methodologies in that knowledge is both constantly being interpreted, negotiated and debated, and as such quantitative or qualitative data should be used if it addresses the issues (Cohen, Manion, & Morrison, 2018, pp. 34–38). By using netnography, constrained by a critical-realist ontological position, it allows me to do the following: treat the appearance of a website, as a form of communication, not as an accurate representation of the reality of STEM activities behind the scenes but rather as an independent reality of the institution in question. It is

this reality that can be compared against the areas of weaknesses exposed in the RAEng report and so inform if a further approach is needed to capture data where knowledge of activities is shared through other less overt means, e.g. teacher networks (examples in Harrison & Shallcross, 2010).

To best address the problem of needing to consider both qualitative and quantitative aspects needed to answer the research questions a mixed method approach was chosen. An exploratory sequential design was used (Creswell and Plano Clark, 2018, pp. 66–67) which had two phases, an initial inductive analysis phase followed by a deductive/quantitative one.

In the initial phase, data was captured from the relevant web pages on the SEREC universities' websites over the week of the 30th July 2018. As there is no standard format to universities webpages nor a singular page that summarises their outreach activities a search engine spider was used to crawl each website. These automated programs examine each page on a website and identify pages that contain particular key words or phrases. This reduces the number of webpages that need to be examined in more detail. To try and ensure the data was relevant to answering the question, these were based on possible terms that a teacher would use if they were looking for outreach activities. The following criteria was used to create the search:

- It must contain "outreach"
- It should also contain at least one of - STEM, biology, chemistry, physics, Engineering, computing, Maths, bioscience, marine, school, college
- Only search within the University's domain name
- Only return pages that, through their metadata, identified as being under two years old (in order to focus on current provisions)

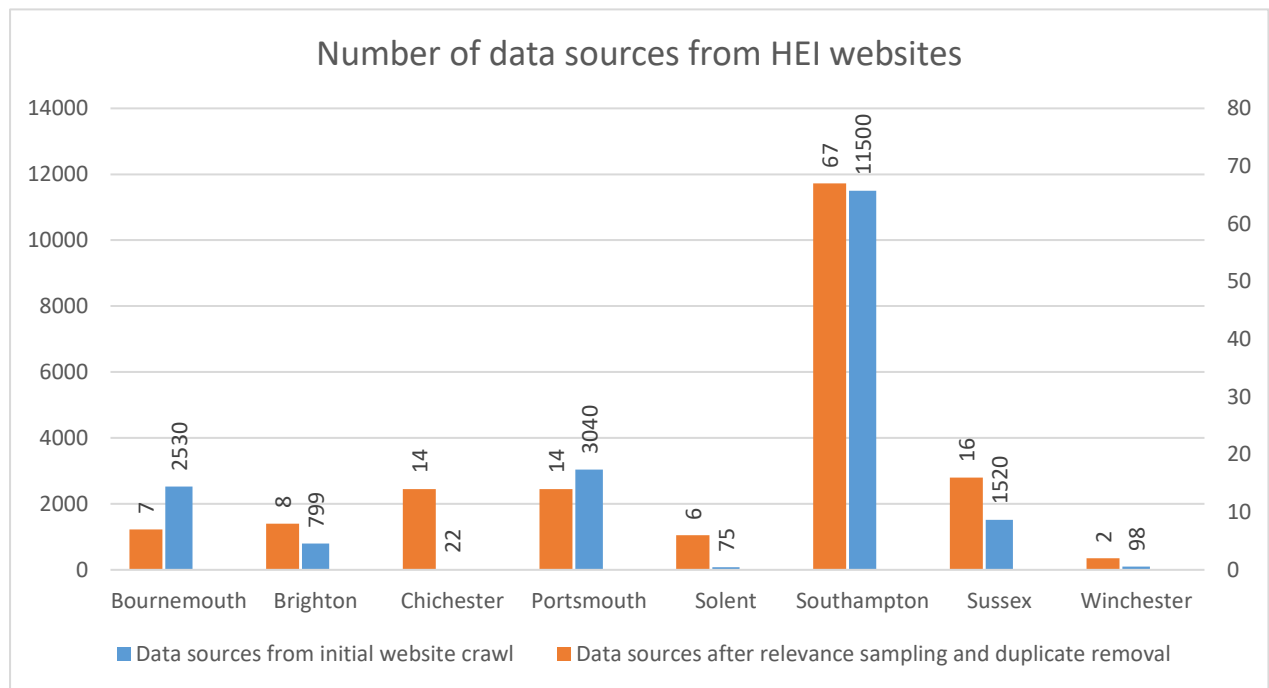
As this produced a large number of sources (Figure 1), relevance sampling (a non-probabilistic technique) was then applied to exclude sources where:

- the terms outreach, schools or colleges only appeared outside the main body of text (e.g. only in the navigation bar)
- web pages, like job adverts or biographical pages, were not explicit in describing current outreach, or referred to activities external to the institution (e.g. through STEMnet).

Large websites tend to use Content Management Solutions to manage the multitude of webpages. This allows the same content to be reused on different pages, where necessary. To remove repeated sources a comparison of text inside relevant HTML body, section and article tags was made on all sources from the same university website. Where there was over 80% similarity, it was manually compared, and one source removed if it was the same. This reduced the population size down to a more manageable 134 sources (Figure 1). The

data collected included non-STEM activities as well as STEM ones, however this was felt to be better than using another form of sampling which may then start to preclude relevant data and bring up possible issues of accurate representation (Krippendorff, 2013, p. 120).

Figure 1- Number of webpages containing possible outreach activity data



Both manifest content, where the outreach activity was explicitly written, and latent content, identifying the underlying meaning behind the words or phrases to identify an activity, (Bengtsson, 2016) was then coded using an inductive approach (done without familiarity of the gaps identified in the RAEng report, and no preconceived ideas of what the outreach looks like at the universities). Abductive inference was used in a number of cases using cues from the wider context of the web page (Krippendorff, 2013, p. 42) to determine what the features of the activity were to enable them to be coded. For example, using photos alongside the text to help identify the audience.

Coding was done in three rounds. An initial round of coding developed five themes - the audience the outreach was aimed at, the type of outreach, the location it takes place, the subject/topic, and the purpose of the outreach. This was then re-examined and revised into more specific codes under each of these themes over two more rounds of coding. This gave a total of 54 codes that relate to five themes of the outreach activities: the audience, location where the activity takes place, the purpose of the activity, the type of activity and the university offering the activity.

To ensure validity of the content analysis the method and coding are explicit (Appendix 1). Also, the intra-rater reliability was calculated by double coding three random pages a week

after the initial coding (Mackey and Gass, 2005, pp. 128–129; Boréus and Bergström, 2017, pp. 28–29). This has an average agreement of 98.55%, with the lowest agreement for a code being 81.24% which is higher than the suggested minimum of 80% by Krippendorff and Bock (2009, pp. 354–356). This was then analysed to identify key themes.

The second phase involved matching the gaps identified in the RAEng report against the inductively derived codes. Of the eight gaps two were excluded as indicated earlier. One as it relates to outreach activities supporting teaching in universities and the other about coordination of outreach, as this sample is of universities associated with the SEREC group which is about discussing and coordinating outreach activities. Two of the gaps in the report make specific reference to engineering (see gaps 4 and 8 in Table 1). In this study it was taken more generically to mean STEM, as Engineering is not part of the National Curriculum and is generally not studied until KS5. This recognises that the promotion of the other STEM subjects is key to developing an interest in engineering (Morgan et al., 2016).

As each gap related to a conditional statement about multiple codes, these were processed using Nvivo's query tool and the text in the source interpreted manually to ensure there was a coherent relationship between the codes. The results were converted to a numerical representation and basic descriptive statistics were used to answer the first question.

To determine if there are any significant relationships between the inductive codes generated about the outreach activities offered by a university and the students who enrol there, the inductive codes were quantitized, a term used by Tashakkori & Teddlie (1998) to relate to transforming qualitative data into a numerical format as seen in Appendix 1, in order to aid analysis. Data on enrolments for the eight universities were downloaded from HESA's (2018) open source data set. The data currently available is limited to data about enrolment based on gender and STEM subjects, which gave some constraints to the analysis. Microsoft Azure's Machine Learning Studio was then used for reviewing the data and calculating the correlations. The statistical test was chosen to allow the comparing of one dependent variable (enrolment) against an independent variable (the inductive code) where both variables are on an interval scale. As the data isn't normally distributed and, because there is likely to be a diminishing return, the relationships were unlikely to be linear a Pearson correlation would be therefore not be an appropriate statistical method to use, and a Spearman correlation more appropriate (Weaver *et al.*, 2018, p. 442). This was confirmed by creating scatter plots of the data. Simple descriptive statistics were then able to be used.

CLOSING GAPS IN OUTREACH PROVISION

It isn't surprising that all the universities' websites had at least one web page which was created by a central recruitment/outreach team, because of the requirement for

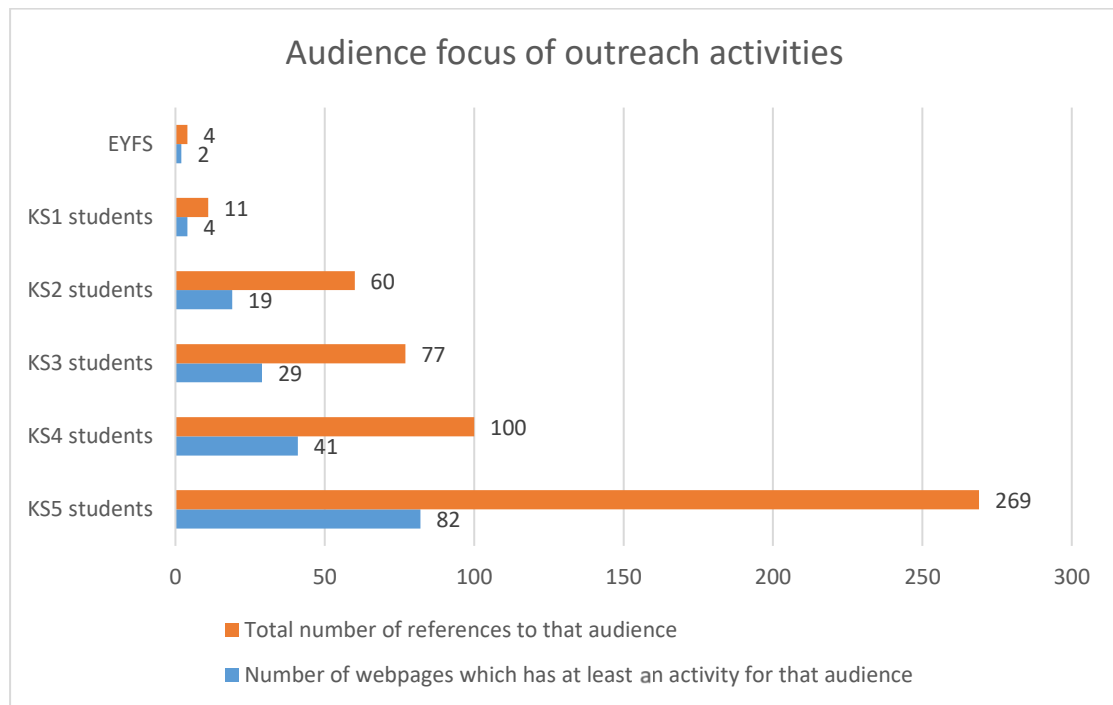
universities to run outreach programmes to raise aspirations the higher education and the development of a National Collaborative Outreach Program by the Office for Students (2019a). It is unsurprising then, that there were more outreach activities aimed at encouraging students to go to university than focusing on enthusing, or learning about, a specific discipline. It is in specific academic department web pages that there are more subject specific activities, the aims being a mix of enthusing and engaging students as well as encouraging them to study this at a higher level. Overall there was a broad range of types of activities on offer from the universities, with talks tending to be more overt in the texts. The activities were more heavily aimed at a KS5 (post 16) audience and reduced through the Key Stages with only two references from one university at an outreach activity aimed at Early Years. It is perhaps the pressure universities are under to recruit that outreach is being used predominantly as a recruitment tool, so we are seeing it more often aimed at an audience where there are immediate gains (see Johnson et al., 2019). A number of the activities offered at the universities where the target audience were specific groups. All universities had ones around widening participation as per their requirements (Office for Students, 2019b). Five of the universities had activities aimed at girls, which relates to addressing a gender gap we see in certain STEM subjects that limits future STEM careers open to them (Macdonald, 2014). Winchester had the only one aimed at service children, as part of research they are undertaken which is informing the Office of Students (2019b) guidance to universities for 2019-20, so it is likely we may see more prominence to outreach activities for this group in future. What was noticeable was there was very little evidence of activities tailored towards those with disabilities or who were BAME which was an gap highlighted in the RAEng report (Table 1).

Whilst there were many activities relating to getting students to continue to higher education, there were about half as many more activities based around STEM subjects as opposed to general information about higher education (e.g. finance or general university life). There were significantly fewer activities based around non-STEM subjects (even taking into account non-specified subjects), which may be due to a lack of worry of the number of students taking these subjects wanting to progress in to higher education with them?

Two universities had very little STEM related outreach activities advertised on their websites. Brighton had only two, relating to the same activity:

“This talk is for students interested in NHS professions including Nursing, Midwifery, Podiatry, Physiotherapy and Social Work.”

Figure 2- More outreach activities are focused on those about to consider going to university than earlier on in their schooling



whilst Winchester only had one reference which STEM was not specifically mentioned

“We can arrange for subject specific talks delivered by University of Winchester lecturers.”

but was inferred as the University offers 59 BSc courses on their website. This highlights the ‘hidden’ outreach activities that are not displayed and the limitations of this work. STEM Sussex provides outreach activities to schools in partnership with various employers as well as the University of Brighton (2019), and it is therefore hard to unpick what activities the University individually provides through this. It is entirely likely that the other universities also have other outreach activities that are not recorded on their website. This paper is just a starting point of understanding what’s being done, with their websites content being indicative of what’s being done.

Integrating the quantitative and qualitative data using a joint display, in a way suggested by Creswell and Plano Clark (2018, pp. 238–243) it is possible to easily compare how outreach activities with specific codes relate to those gaps identified in the RAEng report. It is to be expected that the gap around ‘Improving teaching and learning in the FE sector and promoting practical, technical and vocational pathways to engineering’ (STEM) is not a gap in university outreach provision. All the universities in SEREC have outreach activities aimed at the FE sector, although there may be an imbalance in that the primary aim of most of these activities is to promote a pathway through higher education routes.

Table 1- Number of universities' websites (N) and sources (Ns) that identify where university outreach activities meet the gaps in STEM outreach provision, identified by the RAEng report (Morgan, Kirby and Stamenkovic, 2016), and the inductive codes used to match them.

Gaps in outreach identified in the RAEng report (2016)	N (% of 8)	Ns (% of 134)	Matching inductive code requirements
1. Improving the understanding of, and attitudes towards engineering among young people, their influencers and the public.	6 (75%)	39 (29%)	"STEM subject" AND ("Schools" OR "Colleges" OR "Parents") AND ("Enthusiasing about specific STEM subjects" OR "Improve STEM subject knowledge")
2. Increasing support for teachers of STEM subjects.	4 (50%)	22 (16%)	"STEM subject" AND ("College/Teachers" OR "School/Teachers") AND ("Reference material and resources" OR "CPD and conferences")
3. Greater STEM support in primary schools	3 (37.5%)	12 (9%)	"STEM subject" AND "Primary students"
4. Improving teaching and learning in the FE sector and promoting practical, technical and vocational pathways to engineering (STEM)	8 (100%)	42 31%)	"STEM subject" AND "Colleges"
5. Widening access to under-represented groups	4 (50%)	5 (4%)	"STEM subject" AND ("WP" OR "Girls" OR "Ethnicity" OR "Disability")
8. Provision of more specific careers information on the routes to engineering careers in different sectors, and further advice and guidance on work experience, industry placements and application processes in engineering (STEM)	6 (75%)	11 (8%)	"STEM subject" AND "Careers"

What is interesting is taking it in relation to gap 1 – improving the students' knowledge of the subject or enthusing them about it – two of the universities don't explicitly or implicitly say that they are trying to do this (although it is likely they are, if they do want them to continue to study this at university)!

Only three of the universities reference working with Primary schools around STEM subjects, but with ten of the twelve sources coming from one university it seems that it is still a large gap in STEM outreach provision. If by year 6 (the last year of primary school) a significant proportion of students have already decided that the idea of a career in STEM subjects or studying it beyond the age of 16 (Archer *et al.*, 2013) then universities are making things harder for themselves by not doing more at an earlier stage. Like the focus on students, outreach activities for supporting teachers of STEM subjects is skewed towards the post-16 and secondary side, with majority of sources coming again from one university. As primary teachers are multidisciplinary, they are likely to be in more need of support around STEM subjects which could also help address the issues mentioned before.

OUTREACH AND HE ENROLMENTS

Whilst there is an obligation to provide outreach around widening participation, there can be tensions developed when academics are required, or wish to, deliver outreach activities (Johnson *et al.*, 2019). One of these is perceived value, and so any relationship between outreach activities and enrolment is likely to be of interest. In using the inductive codes created in identifying the elements of outreach activities from the universities in SEREC, there were some interesting correlations with some significant positive associations.

There shows a very strong correlation ($rs[8] = .904762$, $p < .005$) between the number of outreach activities in colleges/post-16 students a university did and the number of female enrolments there. Whilst it is to be expected that there would be a correlation between college outreach activities and enrolment, it is much more pronounced in female enrolment than in male enrolment ($rs[8] = 0.761905$, $p < 0.05$). However, this is reversed when related to outreach activities aimed at schools with males still showing a correlation, but females no longer showing one. Female enrolments also correlate ($rs[8] = 0.790433$, $p < 0.05$) with outreach activities targeted at specific groups, which may be due to those specifically targeted at girls which were STEM focused.

Table 2- The correlation of codes used to identify elements of outreach activities provided by the universities website (N=8) and the number of enrolments by the identified gender. Significance levels calculated from Ramsey's (1989) table of critical values. * <0.05 ($r>0.738$); ** <0.01 ($r>0.881$); * <0.005 ($r>0.9$)**

Inductive codes that relate to the RAEng gaps.	Number of Male enrolments	Number of female enrolments	Percentage of Female enrolments
STEM subject	0.595238	0.404762	0.52381
Colleges	0.761905*	0.904762***	0.071429
Schools	0.738095*	0.642857	0.595238
Parents	0.5545545	0.727393	0.072739
School/Teachers	0.203596	0.407193	0.38324
College/Teachers	0.610789	0.718576	0.179644
Enthusiasing about specific STEM subjects	0.227549	0.167668	0.263478
Improve STEM subject knowledge	0.443122	0.239525	0.455098
Reference material and resources	0.285714	0.142857	0.380952
CPD and conferences	0.238095	0.119048	0.02381
Primary students	0.38557	0.144589	0.734993
WP/Girls/Ethnicity/ Disability	0.574861	0.790433*	0.119763

Table 3- The correlation of codes used to identify elements of outreach activities provided by the universities (N=8) and the number of enrolments by subjects identified as STEM or non-STEM by the Higher Education Statistics Agency. Significance levels calculated from Ramsey's (1989) table of critical values. * <0.05 ($r>0.738$); ** <0.01 ($r>0.881$); * <0.005 ($r>0.9$)**

Inductive codes that relate to the RAEng gaps.	Number of STEM enrolments	Number of non-STEM enrolments	Percentage of STEM enrolments
STEM subject	0.642857	0.404762	0.5
Colleges	0.833333*	0.52381	0.857143*
Schools	0.738095*	0.452381	0.785714*
Parents	0.727393	0.327327	0.836502*
School/Teachers	0.251502	0.251502	0.39521
College/Teachers	0.754505*	0.275454	0.89822**
Enthusiasing about specific STEM subjects	0.347312	0.011976	0.299407
Improve STEM subject knowledge	0.514979	0.275454	0.323359
Reference material and resources	0.261905	0.142857	0.52381
CPD and conferences	0.285714	0.238095	0.285714
Primary students	0.586846	0.240981	0.409668
WP/Girls/Ethnicity/ Disability	0.598813	0.19162	0.742528*

Though STEM outreach activities themselves don't appear to have any correlation with the identified gender of those enrolling. It is interesting to note then, that there is a correlation between those activities target at specific groups and the percentage of STEM enrolments ($rs[8] = 0.742528$, $p < .05$) which may indicate this audience choosing STEM disciplines.

There are several correlations shown in the numbers and percentages of STEM enrolments. Activities aimed at post-16/college students correlated with the number of STEM enrolments ($r_s[8] = .833333$, $p < .02$) as well as the percentage of STEM enrolments ($r_s[8] = .857143$, $p < .02$). This was also true for activities aimed at post-16/college teachers, for both numbers ($r_s[8] = 0.754505$, $p < 0.05$) and percentage ($r_s[8] = .89822$, $p < .01$) of STEM enrolments; as well as those aimed at students in secondary schools, for both numbers ($r_s[8] = 0.738095$, $p < .05$) and percentage ($r_s[8] = 0.785714$, $p < .05$) of STEM enrolments. Even activities aimed at parents also had a correlation too with the percentage of STEM enrolments ($r_s[8] = 0.836502$, $p < .02$). This is contrast for non-STEM subjects which had no correlation with any of the inductive codes. It is interesting to see then that the activities who are identified as being focused around a particular STEM discipline has such a weak correlation to the number and percentage of STEM enrolments. That it may be a combination of various outreach activities they are exposed to by the university, both subject focused and raising aspirations to continue in higher education, that causes the correlations we see. This would match with the idea that ongoing outreach programs are more effective than one off approaches (Macdonald, 2014).

It would seem then, that outreach activities, shown to be undertaken on universities websites, do have an impact on enrolment which isn't just limited to the stages just before filling in a UCAS form. Whilst not statistically significant, the correlation numbers between activities aimed at Primary and the percentage of female enrolments, as well as the difference between STEM and non-STEM enrolments maybe needs exploring more deeply, especially considering the small number of sources to work with.

DISCUSSION

The amount and type of outreach provision offered by universities involved in the South-East Regional Engagement Consortium is varied. This is clear through the number of web pages relating to outreach activities on their websites, which bears no indication of the size (number of undergraduate students) of the institution. Southampton having nearly five times as many pages relating to outreach as Portsmouth, being of comparable size, Chichester, despite having fewer students, has seven times as many pages as Winchester. This may possibly indicate how each institution views the importance of outreach, at least to the degree they are using their websites to communicate what they do to the world.

Where there is increased outreach provision, it tends to indicate more subject specific outreach activities being done. In contrast those showing limited outreach provision tended to centre around the subject of continuing in Higher Education rather than on STEM subjects. This shouldn't be unexpected as universities shift away from focusing on civic good as a consequence of marketisation and need to recruit (McCaig, 2015). Overall, around

twice as many outreach activities have the purpose of encouraging continuing in education (particularly to university) compared to improving STEM knowledge or enthusing students' interest in those subjects. It may be, however, that some subject or discipline specific activities aimed at continuing in education are being delivered by academics. Who, being able to draw on their pedagogical and subject knowledge, are more likely to also engage and enthuse students from schools or colleges in those subjects or identify career paths (examples in Harris & Ridealgh, 2016) which this netnographic approach isn't able to fully capture.

There are specific STEM outreach activities provided within this SEREC group of universities though. When these are compared to the weaknesses, or gaps, in provision identified in the RAEng report's evaluation of STEM outreach one thing particularly stands out. All the universities are involved in delivering a number of STEM outreach activities to post-16 providers. This appears as a strength, rather than a weakness, as suggested in the report, which may be because of the need for universities to recruit, as mentioned above.

There also doesn't appear to be a gap in these universities provision around "improving the understanding of, and attitudes towards engineering among young people, their influencers and the public". In fact, taking into account the limitations of the approach used here, as mentioned previously, there may even be higher incidences of this taking place. Similarly, around the suggested weakness around STEM careers information. It's been possible to capture that most of the SEREC group of universities are doing this, but a different approach that allowed a more detailed examination of what happens in delivery of STEM outreach activities may show greater incidences.

Whilst it appears universities are doing something to address the outreach provision gaps identified by the RAEng, it is notable that the reach of universities is going to be limited. They have finite resources and provision is likely to be focused on those schools and colleges in the immediate vicinity. Those schools outside of this reach are still likely to be missing out unless other providers can also offer this. Universities then have the potential to be able to use their experiences in these areas to support other providers offering STEM outreach around these areas.

Unfortunately, some gaps do remain. Outreach provision for Primary schools is significantly lower. Again, this may relate back to the need to recruit, a stronger focus on WP, and the view that use of resources in this will see little immediate pay off. This in contrast to the ideas that students' engagement with STEM is most strongly influence by their experiences at Primary (Council for Science and Technology, 2012) and a number of students will have already decided that STEM is not for them by the end of Primary (Archer *et al.*, 2013). By increasing support to Primary teachers though, who often lack specialist STEM knowledge (Wellcome Trust, 2014), universities could start to close two of the outreach provision gaps,

which could also benefit them in the long term. Engaging with the teachers allows them to reach many more students thus allowing the development of more STEM engaged students at later key stages in their education. The risk being at the expense of their university's name not being so overtly connected to this and other universities benefiting in recruiting from the bigger pool of STEM engaged students they helped create. This can be tempered though by offering a broad program of outreach activities for each stage, with more direct input to the students as they get older, which is already suggested here to have an impact on enrolment figures; or, pragmatically, if most universities did this everyone benefits.

There is also still a gap in provision relating to widening access to underrepresented groups and, as the RAEng report noted in their findings, this is significant in the lack of specific focus towards those with disability or BAME. If the correlation shown with focused activities for girls and female enrolment is an indicator though, activities focused on these groups could also increase enrolment in these areas. The RAEng report also indicated that addressing the gaps will help address the lack of people progressing into STEM careers. This should be of particular interest to universities, as this will relate to increasing the number of enrolments on STEM courses. It is worth noting then, that where SEREC universities seem to be addressing this gap through outreach to colleges, both to teachers and students, there is a significant correlation to the number of male and, more specifically, female enrolments. This also applies to those who enrol on STEM courses, although not on non-STEM courses. This may be in part due to there being a larger focus on STEM outreach activities, with five times as many references to STEM activities on the websites than non-STEM. However, there does not appear to be any strong correlation with a specific subject focus of the activity, instead it is probably being exposed to a range of activities. It is encouraging to note that there is also a relationship with STEM enrolment and outreach aimed at parents and schools. Whilst correlation does not mean causation, it is worth examining this more deeply as justification in investing in STEM specific outreach, to better understand how it may be aiding recruitment.

CONCLUSION

The UK STEM education landscape report (Morgan, Kirby and Stamenkovic, 2016) suggested that there were several gaps in outreach provision that needed to be addressed if we wanted to see a bigger, more capable, STEM workforce in the future. It appears, considering what is shown on the websites of a collection of universities in Southern England is indicative of what is happening that universities are addressing some of these gaps. Whilst this is in part due to requirements laid down by the Office for Students (2019b), it is also because of their own needs to recruit.

Subject specific STEM outreach activities generally require the input of academics, whose time and workload is already stretched (Johnson *et al.*, 2019), so the audience is predominantly aimed at Post-16 students, who are about to make choices about going into higher education. Activities aimed here do show recruitment benefits.

There are some activities offered, possibly through civic duty or recognising longer term benefits, to students early on in education or aimed at specific underrepresented groups in STEM but this still appears a weakness as identified in the RAEng report. The limitations of this study though are not enough to confirm this and so further investigation is required. The lack of evidence on the universities websites though, in comparison to those aimed at post-16, may at least suggest that the perceived value of outreach in these areas is not as high asking the question why, when these activities may also benefit the universities' in the long term?

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APPENDICES

Appendix 1- Codes used for content analysis and the number of sources the codes appeared in, and the number of times the codes appeared in total.

Code group	Code	Sources	References
Audience	Characteristics	39	137
	Boys	1	1
	Disability	7	7
	Ethnicity	1	1
	Girls	9	14
	Refugee	1	1
	Service Children	2	18
	WP	19	50
	Colleges	101	480
	KS5 students	82	269
	Teachers	48	99
	education professionals	28	50
	Parents	24	55
	Schools	85	175
	Primary students	44	82
	EYFS	2	4
	KS1 students	4	11
	KS2 students	19	60
	Secondary students	63	179
	KS3 students	29	77
	KS4 students	41	100
	Teachers	61	134
Location	At school	64	161
	At University	72	159
	Other	16	33

Purpose	Continuing in education	74	307
	Enthusing about specific subjects	69	191
	Enthusing about specific STEM subjects	52	142
	Improve subject specific	73	198
	Improve STEM subject knowledge	56	154
	Soft skills	26	87
	Careers	41	83
	HE	64	300
	Non-STEM subject	31	105
	STEM subject	92	468
	Unspecified specific subjects	34	91
Type	Awards event	10	16
	CPD and conferences	44	140
	Network	13	29
	General events or activities	60	146
	Project-programmes	55	141
	Mentoring	5	7
	Reference material and resources	33	103
	Talk	72	220
	Tour-exhibitions	40	69
	Workshop or activity	93	397
University	Bournemouth	7	
	Brighton	8	
	Chichester	14	
	Portsmouth	14	
	Solent	6	
	Southampton	67	

	Sussex	16	
	Winchester	2	

Paper 4: Developing the through-career outreach capabilities of manufacturing engineering graduate students: Lessons from the 'How stuff gets made' project

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KEY WORDS: outreach, manufacturing, pilot, primary schools

ABSTRACT

This paper reports on the planning, implementation and review of a pilot project to address a gap in current approaches to raising awareness of manufacturing concepts amongst primary age children and their teachers. An approach was designed and piloted that sought to help address this gap through the development of outreach capabilities amongst manufacturing engineering graduate students and researchers to develop their own capabilities, and to design and evaluate manufacturing outreach resources for use in primary schools. In this paper we first present the background to this topic then review the relevant literature. We then describe the method used to design and deliver the project, and to capture data to assess its effectiveness. Next, we present the key findings and discuss the outputs and outcomes of the project. Finally, we draw our conclusions and highlight areas where further work could be most usefully targeted.

BACKGROUND / CONTEXT

The broad goal of this project¹ was to pilot a new approach to help address the inaccurate and/or incomplete perceptions of 'manufacturing' held by UK primary schoolchildren and their teachers. Research reveals that perceptions that are developed among primary age pupils can have a strong impact of subject preferences and, eventually, of career choices (Bryant, 1974), and this is particularly true for STEM subjects (RAEng/ETB, 2007). Whilst there are numerous examples of projects targeting the development of positive attitudes to STEM at primary level (RAEng, 2016), relatively little was found that was targeted at manufacturing (which, more broadly in the UK economy, research has shown as a relatively poor perception (Livesey, 2012)). Given the critical role that manufacturing plays in the UK

¹ "How does stuff get made? Developing primary manufacturing outreach capabilities". This project was funded via the Royal Academy of Engineering's 'Ingenious' awards programme and ran from May 2017 to April 2018.

economy (Oxford Economics/MTA, 2018) and on-going skills shortages reported by many firms (Engineering UK, 2018), this pointed us to the need to focus on primary level, manufacturing outreach. Our attention then focused on selecting possible methods to address this issue.

LITERATURE REVIEW / RATIONALE

Our review of possible approaches revealed some challenges faced by previous attempts to address this issue. Key amongst these were issues of bounded rationality (Simon, 1991) and absorptive capacity (Zahra and George, 2002) i.e. though resources might be available to address this need, primary school teachers who had identified such a need did not necessarily have the time to find, review and select appropriate resources from the wide possible range of options. In addition, even if appropriate resources were identified and accessed, in our initial interviews teachers cited a lack of confidence in their ability to deploy such resources effectively. In parallel, it was reported during our interviews that some outreach interventions do not have an enduring impact: they only provide a short-term 'spike' in interest that does not endure.

AIM AND OBJECTIVES

The project reported in this paper had three aims: (i) to help primary school children learn about manufacturing engineering; (ii) to develop graduate engineer's outreach delivery skills and (iii) to engage with primary school teachers to align outreach activities with classroom learning and the curriculum. The objective of this paper is to: describe the process of designing and delivering the project; explain how data was captured to assess effectiveness; and reflect upon lessons learned from this project.

METHODOLOGICAL APPROACH

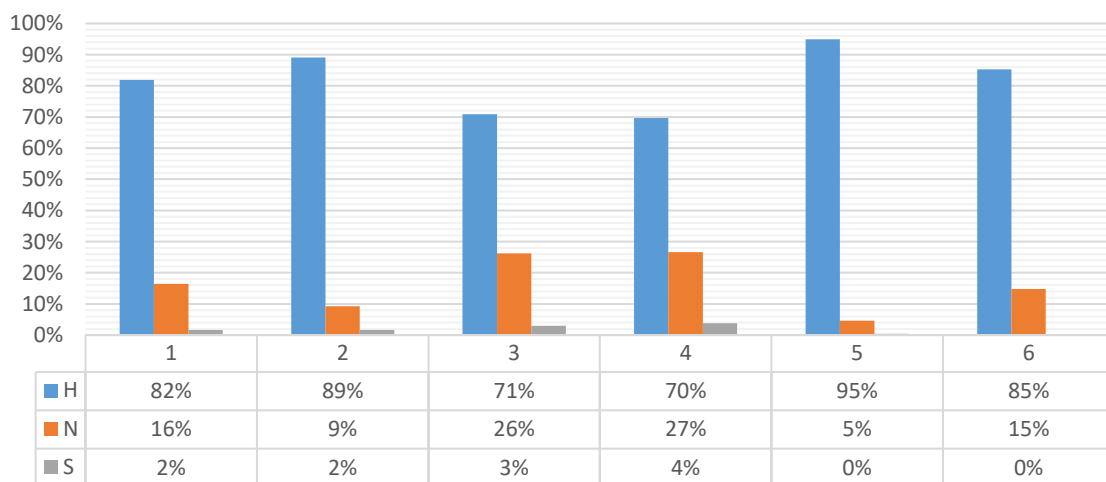
The project was split into phases: training for graduate engineers, resource development and delivery of the activities developed. The training consisted of two workshops led by a Senior Lecturer in Primary Science /Teacher Education at the University of Cambridge Faculty of Education. The workshop focused on effective design of primary school level outreach activities and age-appropriate delivery. Through partnerships with local state primary schools set up with support from the Faculty of Education, resources were developed and refined with input and feedback from educators. The activities were then delivered to children from the partner schools, as well as other schools who had heard about the project through various channels and wished to be involved.

The graduate engineers/researchers and children were surveyed to evaluate their perceptions of the effectiveness of the project. The children's surveys required a response to six statements where three choices were given – a sad, neutral or happy face. For the graduate engineers/researchers, a more extensive survey was prepared with responses in the form of multiple-choice answers and free text input. Only the children who participated in a full day of manufacturing outreach activities were given the questionnaire which was completed immediately after the activity day. The total number of children cited as being involved with the project includes those that experienced a shortened activity, typically a half-day session. Thus, the total number of children who were involved in any stage of the project was 627 but the total who were asked for (and did complete) feedback was 237. All 12 of the graduate engineers were asked to fill out a survey, however only 9 responded.

KEY FINDINGS

Figure 1 the results from the questionnaires given to the children to complete.

The number of happy, neutral or sad responses to statements from 237 children participating in day long activities



NO.

STATEMENT

1	I now know some of the things that engineers do.
2	I learnt something new about engineering.
3	I now know something about how engineers might make people's lives better.
4	The day made me want to find out more about engineering.
5	I enjoyed the day.
6	I think that people in other classes would enjoy the work we did.

Figure 2 the responses pertaining to the project goals from the graduate engineers.

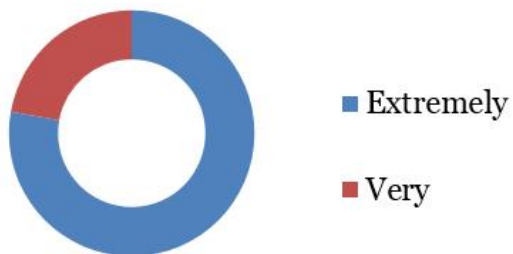
100% more confident to engage



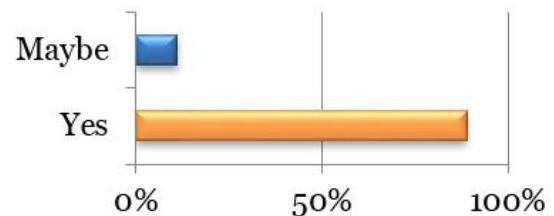
Skills workshops usefulness



Likelihood of participating in outreach again



Will skills gained be helpful in your career?



DISCUSSION

The first objective of the project was to teach primary school children about manufacturing engineering. The results in

Figure 1 show from the children's perspective this goal was achieved through the project. Only 2% of participants felt they did not learn something new about engineering and 89% thought that they had. This also indicates that the activities designed were set at the correct level so that children would not be alienated by the difficulty but instead felt that they could immerse themselves in the day. The collaboration with teachers in creating activities seems to have successfully ensured that the activities were age and audience appropriate. 95% of the participants enjoyed the day, and no participants responded negatively. This is a very encouraging result as enjoyment is motivation for repeated participation. Another promising result is that 70% of the children surveyed want to find out more about engineering. However, this also highlights an area for potential project development because once the activities were delivered there was no repeated contact with the children and the engineers.

The development of the outreach skills of the graduate engineers/researchers' outreach skills was another aim of the project. Some of the key findings from the questionnaire given to the engineers/researchers are shown in

Figure 2. All participants reported that they were more confident to engage with primary school children about manufacturing, they were all extremely or very likely to participate in outreach activities again and they all considered the skills they developed to be possibly or definitely useful for their future career. However, the way in which these skills were developed within the project clearly needs refining as there was not a clear consensus amongst the respondents as to whether the skills workshops were useful. Compared to the other results in the questionnaires, this highlights the area that requires the most attention in order to improve the training aspect of the project.

CONCLUSIONS & RECOMMENDATIONS

The objective of this paper has been to describe the process of designing and delivering the project; explain how data was captured to assess effectiveness; and reflect upon lessons learned from this project. The results presented above seem to show that 'How Stuff gets Made' project has helped 627 primary school children increase their awareness of manufacturing and helped to develop the outreach skills of a small cohort of graduate manufacturing engineers/researchers. A key lesson from this project has been the role of the collaboration between the University of Cambridge Institute for Manufacturing and the Faculty of Education. This was a crucial element in forming relationships between the engineers/researchers and school teachers in order to create suitable, relevant activities. In addition, the role of Faculty of Education of identifying and liaising with local state primary schools to set up, deliver, and capture feedback from the pupils was invaluable. This has also provided a platform for ongoing collaboration. Results from the questionnaires highlighted that the skills workshops delivered by the Faculty of Education require further consideration as there was no consensus on their usefulness. For future university outreach capability development projects, it is recommended that collaboration is sought out with the relevant education faculty, and that further consideration is given to the design and delivery of the most suitable training methods for engineers/researchers to support development of their outreach capabilities.

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Paper 5: The making of engineers: why we need to consider pre-university education when conducting Engineering Education Research.

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KEY WORDS: Primary school, Qualitative, discussion, misconceptions, career choices

ABSTRACT

Reflecting on the findings of a PhD study investigating engineering education in England at Primary education level, this paper highlights the importance of research focused on pre-university when considering the effectiveness of engineering education, especially the recruitment of students onto engineering career pathways. Focusing on the impact that EER can have on teaching within the upper primary school setting (children aged 9-11), the importance of discussion with this age group is emphasised. Discussion allows children to voice, question, and develop their understanding of engineering, allowing for misconceptions to be challenged, and thus building an accurate definition of engineering at an age where career paths are already being formulated. The paper concludes by arguing that research conducted at primary level is of great importance to the EER community, as delivery of effective engineering education at this age may positively impact recruitment and diversity of future cohorts of engineers.

INTRODUCTION

The research reported in this paper was carried out against the recognised skills shortage in engineering (CBI, 2015) and the growing unrest of the engineering professional bodies concerning the current provision of engineering education (Banerjee, 2017; Engineering UK, 2017; IMechE, 2016).

A brief examination of five engineering education journals via their web pages is presented in Table 1, revealing that the majority of papers published during 2018 maintained a HE focus. As engineering does not appear as a distinct subject in many education progression routes, this focus within the literature is not unreasonable. However, it does identify an area of the education system where little data have been collected to inform design and delivery of learning activities regarding engineering education.

Table 14: Percentage of papers published in 2018 that have a HE and pre-HE focus.

Journal	No. of papers published in 2018	% of total focused on HE	% of total focused on Primary and Secondary education
International Journal of Engineering Education	141	92	4
IEEE Transactions in Engineering Education	15	100	0
International Journal of Engineering Pedagogy	38	28	16
European Journal of Engineering Education	61	74	5
Journal of Professional Issues in Engineering Education and Practice	20	75	0

As engineering does not explicitly form part of the national curriculum in England, it has been concluded that the majority of children receive an ad-hoc provision of engineering education during the compulsory years of education (Clark and Andrews, 2010). At the current time, this provision is delivered by a variety of organisations (STEM Directories, 2018; RAEng, 2016) with little monitoring or evaluation of outcomes made visible (Bultitude et al., 2010).

LITERATURE REVIEW

Whilst research focused on engineering education prior to university is scarce in the UK, there has been research conducted into STEM education more widely. In-school STEM activities remain the focus of provision of engineering education prior to the age of 16 in the UK, and teaching quality and curriculum focus have been identified as influential factors in children's decisions to study STEM (Science, Technology, Engineering, and Mathematics) subjects (RAEng, 2016; IMechE, 2010; Clark & Andrews, 2009). The importance of this is not questioned, science and maths subjects continue to be dominant pre-requisites for studying engineering at university and so decisions to not study these subjects in the final years of pre-university education (at age 16-18) is rightly seen as a barrier to progression to engineering (IMechE, 2010; IET, 2008). However, the use of science engagement and aspirations may be a misleading metric for evaluating engineering progression as research suggests that primary school children (aged 9-10) hold different perceptions of science and engineering (Silver & Rushton, 2008). This indicates that whilst the EER community can learn from science education research, it should not be assumed that an interest in science indicates an interest in engineering and so engineering focused research at pre-university level education is important.

Archer et al. (2010) discovered that whilst children may have positive attitudes towards science as a school subject, they were able to hold concurrently negative views of science as a career due to a perceived mismatch between their own identity and that of being a 'scientist'. Whilst the focus of this work was on science, the identification of constructions of identity in relation to science careers at this age may hold implications for engineering also, especially as it has previously been suggested that students are largely unaware of what engineering entails (Clark and Andrews, 2010a). A statement supported by the findings that children hold inaccurate perceptions of engineering, focused around transport and fixing/repairing (Silver & Rushton, 2008; Broadbent et al., 2018). Although inaccurate perceptions of engineering may not deter all children from progressing to study engineering, inaccurate perceptions of engineering concerning stereotypes of engineers may actively dissuade young children from developing an interest in becoming an engineer (Silver & Rushton, 2008), and this may be especially prevalent for girls (Master & Meltzoff, 2016).

The importance of the career aspirations held at a young age has been seen in relation to progression rates in both science and engineering. A US study tracking students through high school (Tai et al., 2006) concluded that students who held science career aspirations between the ages of 12 and 14 were more likely to progress to hold a physical science or

engineering degree than those who did not hold any such aspiration at this age. However, there is little understanding of how the current provision of engineering education shapes these career aspirations, further emphasising the importance of a pre-university focus to engineering education research if the publicised deficit in qualified engineers is to be effectively tackled in the future.

The evidence regarding the provision of pre-university engineering education presented in the literature has been dominated by quantitative evaluations of Engineering Education Activities (EEAs), with mixed conclusions being reported. Lauchlan (2017) used pre- and post-tests with participants and a control group of students across 16 of the schools who had participated in the IET Faraday Challenge, a one-off engineering activity delivered to secondary school children in Year 7 (age 11-12). It was reported that no statistically significant differences were recorded between participant and non-participant attitudes to STEM subjects, but that the activity appeared to promote positive perceptions of STEM and of future career options. Banerjee (2017) used student data to investigate the correlation between engagement with STEM activities during Key Stage 3 (KS3) (age 11-14) and KS4 (age 14-16) and progression to study STEM subjects at A-Level. It was concluded that no measurable impact on continuation was found, although a greater impact was visible for those who had participated during KS3 and KS4 rather than KS4 only, indicating that earlier intervention may improve outcomes of participation. Indeed, this is supported by research into younger children's perceptions of engineering, where a study in the US found that following a year of collaboration between professional engineers and the children's school (including sessions run by the engineers and taught content co-created between the engineers and the teachers at the school), children's perceptions were improved (Thompson & Lyons, 2008). This research also utilised engineering role models, the focus of an evaluation conducted by the National Foundation for Education Research (NFER) in 2013 into the STEM Ambassador programme that reported that participation in activities that involved role models led to increased STEM career aspirations. With outcomes of participation in learning activities designed to facilitate engineering focused learning remaining unclear, further research into this area is crucial to enable informed design and delivery of activities to promote the development of accurate perceptions of engineering in children at a young age.

RESEARCH QUESTION

The PhD study from which this work is drawn aimed to answer the following research question:

How does participation in an engineering education activity at age 9 – 10 (Year 5 in England) affect children's perceptions of engineering as a career at age 11 – 12?

The paper presented here focuses on one aspect of the data collected in order to answer this question, exploring the children's reflections on their experiences in terms of the impact that the structure of the EEA had on the outcomes of participation.

METHODOLOGICAL APPROACH

Based in a constructivist paradigm, a case study methodology utilising a grounded theory approach to data collection and analysis was used in this study. Exploratory observations of the children's participation in the EEA provided a grounding in the activity and context for the data collection and analysis, and semi-structured group interviews enabled data to be collected from which the key concepts of participation were identified. This paper presents one facet of these findings, that concerning the importance of discussion regarding engineering within the structure of an EEA. Verbatim quotes are presented to evidence the findings of this research, directly beneath each quote is the gender consistent pseudonym, case, and age of the child to whom the quote is attributed.

Two rural schools in England where an engineering education activity was being delivered to the Year 5 cohort (children aged 9 – 10), participated in this study, known as Nant School and Phren School. The focus of this research was the children's experience and so their perspective was sought. Fieldwork was carried out between January 2016 and December 2017, semi-structured group interviews were conducted with the children from each case, with interviews occurring once each school year between Year 5 and Year 7. Interviews with the adults in each case were also conducted towards the end of the research to gather additional information about the cases and to check for researcher bias in the interpretations of the data collected. A total of 47 children participated in the observations and interviews, this number was not constant across the interviews as inevitable drop-out occurred, most prominently during the transition between Year 6 and Year 7. 47 children

were initially interviewed during Year 5 (19 from Nant School and 28 from Phren School), 46 of these children were interviewed during Year 6 (17 from Nant School and 28 from Phren School), and 29 were interviewed during Year 7 (3 from Nant School and 26 from Phren School).

Ethical approval was sought and granted for this project, and both procedural ethics and ethics in practice were observed during the study as advocated by Guillemin and Gillam (2004).

KEY FINDINGS

In both cases the EEA was observed prior to the interviews conducted with the participants, during the interviews at each stage the children were asked to reflect on what they thought engineering was and what they recalled about the EEA they had participated in. Although the EEAs in each case were different, both of the activities were interactive and engaged the children in processes associated with engineering (designing, making, testing, evaluating). The children were informed that they were taking part in an engineering activity at Nant School although this introduction was not as clearly observed at Phren School. Neither activity was observed to provide a clear explanation of engineering to the children or engage the children in dialogue about what it means to be an engineer. When reflecting on their experience of the EEA, uncertainty regarding whether the children had known the activity was related to engineering was evident, and where children did relate the activity to engineering this was done so succinctly with little expansion as to why or how the activity was related to engineering.

Yeah the toys one they said it was engineering.

(Scott, Nant School, Year 6)

To learn about engineering [...] I don't know [why it was to learn about engineering].

(Chris, Nant School, Year 6)

I don't think they did [tell us it was engineering] I think they just said, I think we already knew about what we were doing and then they just said they'd, you were put in groups and your target, what you were gonna try and make and the steps and it, I don't think they ever said does anybody know what this is like engineer or anything.

(Sue, Phren School, Year 7)

I just thought you were making, I didn't, I thought it was, I didn't really know what we were doing.

(Ellen, Phren School, Year 7)

When reflecting on the exposure to engineering that the children had experienced during their schooling, it appeared that 'engineering' was not used within the vocabulary of the schools.

At school we don't really talk about it [engineering].

(Bryony, Phren School, Year 7)

Cos before you came in they didn't actually mention engineering.

(Becka, Nant School, Year 7)

I just think that it was like you coming back and talking about all this again because I completely forgot until now.

(Ruth, Phren School, Year 7)

I don't really think about it [engineering] and I've never really been like told what it is properly so I haven't really ever like thought about it because I don't really know what it is.

(Sue, Phren School, Year 7)

In addition, during the interviews at each stage of the research, questions regarding engineering were raised by the children and uncertainty was demonstrated in the children's descriptions of engineering.

Yeah would you say engineering was building a summer house? Building anything?

(Ella, Nant School, Year 6)

Is it something to do with like engines and stuff like transport?

(Matt, Phren School, Year 7)

...I'm not really sure if it would go under engineering...

(Ellen, Phren School, Year 7)

Whilst it appears that children have questions about engineering that go unanswered, interviews with adults from both cases revealed areas within the taught curriculum that they felt embodied engineering, suggesting that although staff believe that children are exposed to engineering within the schools, the engineering content may not be made explicit to the children.

I don't see it [engineering] as necessarily as just a discrete unit, I think it's an area that links and feeds into many other areas of the curriculum.

(Head Teacher, Nant School)

...in science week always do an engineering task even if it's, spaghetti and marshmallows or in the past, depending on how much energy we've got they paper roll [...] and then they build structures with nuts and bolts, and we've got this tubing and they do a roller coaster.

(Science Teacher, Phren School)

DISCUSSION

The data presented illustrates an apparent lack of space provided for discussion regarding engineering within the observed EEAs, as well as indicating that there was an absence of the word 'engineering' within the school environment. In a previously published finding it was seen that inaccurate perceptions of engineering were held by the children involved in this study (Broadbent et al., 2018), indicating that misconceptions about engineering are prevalent even when children participate in an EEA. The finding that the children may not have been provided with an adequate forum in which to articulate and discuss perceptions of engineering could provide a reason for this.

The two EEAs observed both required the children to participate in a hands-on activity with the goal of creating a product, but neither were seen to provide any context as to why these products were to be made and there was minimal discussion concerning engineering observed during the activities. This lack of explicit discussion regarding engineering and the positioning of the activity within an engineering context is considered important due to the concept of discussion being identified within the interview data. Therefore, it may be the case that activities that do not actively engage children with discussions about engineering do not build accurate perceptions of engineering for the participants. Although we may talk about activities being 'engineering', participation may not equip children with an accurate perception of what engineering entails.

It has been stated in relation to the learning of scientific principles that, "instruction in any subject matter that does not explicitly address students' everyday conceptions typically fails to help them refine or replace these conceptions with other that are scientifically more accurate" (Bransford & Donovan, 2005, p. 400). It is noted that there is an assumption in this statement that children hold preconceived ideas, and that this cannot be guaranteed within the current research findings. However, it is possibly that the EEAs did not adequately acknowledge and address the perceptions of engineering that were held by children at the time of the activity. Alternatively, it is possible that participation led to the formation of inaccurate perceptions of engineering, which were not addressed and challenged either during the activity or subsequently.

Whilst activities fail to challenge inaccurate perceptions of engineering it is unlikely that increases in the number of children aspiring to engineering careers will be seen; however, there is also a possible implication for the diversity of children progressing to engineering careers. If narrow perceptions regarding engineering as fixing and relating to transport

persist within future generations, it is possibly that only those children who are interested in these areas will aspire to become engineers. Without discussion highlighting the diverse field of engineering, and the impact that engineers can have on the lives of others, these perceptions may persist, thus limiting the number of children aspiring to be engineers.

Discussions about engineering may provide the opportunity to inform and challenge inaccurate perceptions of engineering, without this element it is possible that participation in EEAs will be unable to assist in the development of accurate perceptions of engineering. However, it should be noted that due to the small sample size these findings are grounded within the context of this research and conclusions are presented to be used to inform future research aiming to examine the relationship between discussion and accuracy of perceptions of engineering, and thus challenge and expand this finding. As only two EEAs were observed it can not be stated that these are indicative of the activities currently provided to schools across England and so conclusions regarding the efficacy of the current provision of pre-secondary engineering education nationally cannot be made. However the structure of the activities has been seen to be similar to the description of other activities and although the activity at Nant School was delivered by the class teacher and therefore would be unique to the school, the activity at Phren School was delivered by an external provider who delivers similar activities regionally.

CONCLUSIONS & RECOMMENDATIONS

In conclusion, this paper presents one aspect of the research findings relating to a PhD study exploring outcomes of participation in an EEA for primary school children. The findings indicate that discussion about engineering was lacking from the children's experience of the EEA, and in their educational journey more widely, but that this may be one way in which inaccurate perceptions of engineering are addressed and modified.

The work presented in this paper focused on a small sample within a particular geographical area, and further research is needed to examine the findings of this research within other contexts. However, it is recommended that providers consider their own definitions of engineering prior to engaging children with an EEA, and that they openly discuss engineering with participants, acknowledging and challenging inaccurate, narrow perceptions of engineering during their delivery of EEAs to children.

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Paper 6: Are We (Engineering Education) Missing Engineering Student Potential?

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KEY WORDS: STEM Pipeline, Inclusive Engineering, Engineering Recruitment

SUMMARY

EngineeringUK (2018) has estimated that the UK currently has an engineering graduate-level shortfall of at least 22,000 per year. In the case of the South East, employers report that they struggle to recruit and keep engineers. Compounded by the fact that, in the South East of the UK, the provision of university level Engineering Education is somewhat limited, Engineering Employers find they have no option but to recruit from outside Kent. The lack of provision in the area also means that potential engineering students from Kent are forced to leave the area to study Engineering (and when they do so, typically do not return). In an attempt to address this issue Canterbury Christ Church University has received £13.1M National and Local Government funding to develop Kent and Medway Engineering, Design, Growth and Enterprise (KM-EDGE) Hub. The aim of KM-EDGE Hub is to address the South East "Engineering Pipeline" challenge through the provision of a new School of Engineering, Technology and Design at Canterbury Christchurch University. The new School will be equipped with resources to support inclusive Engineering and Technology Undergraduate, Postgraduate and Higher / Degree Apprenticeship Programmes for the South East; producing industry ready apprentices and graduates for employment within the local area.

Commencing with the research question "*What potential local pipeline of students could be accessed to study at the new regional engineering education provision in Kent and Medway?*", this paper presents data analysis of the 2017 Kent and Medway STEM GCE. 'A' level results in Maths, Further Maths and Physics. These subjects are those which are generally studied by students wishing to enter Engineering UG Programmes across much of

the UK. The paper also asks whether the Engineering Education Sector is 'missing' potential students in its marketing and recruitment processes.

BACKGROUND / CONTEXT

Currently in Kent and Medway the Production, Manufacturing, Professional, Technical and Scientific Business Sector contributes a Gross Value Added of over £9112M to the local economy; this equates to 23.4% of Kent and Medway business economy (Kent.GOV.UK, 2018). Such enterprises typically employ engineers, technology and design professionals.

Historically in Kent and Medway the Engineering Higher Education provision has been somewhat limited. This means that those students wishing to enter a career in Engineering, and who possess the necessary prerequisite GCE 'A' levels in Engineering, Maths, Further Maths and Physics, (Cornock Cook, 2017) have no option but to leave the area to study. For a variety of reasons increasingly high numbers of students are selecting to live at home, or remain near to their parents' address, when choosing a University. In Medway & Kent this means that for some students, the option of studying for a Degree in Engineering simply doesn't exist. To address this *leaky pipeline* Canterbury Christ Church University has received national and local funding to create innovative inclusive and industry co-designed engineering education curriculum provision; The Engineering, Development Growth Enterprise Hub (EDGE Hub) which aims to support the growth of South East Enterprises and economy.

AIM AND OBJECTIVES / RESEARCH QUESTION(S)

The EDGE Hub has aspirations of growing the South East economy by supplying 'Industry-ready' Engineering graduate and apprenticeships to local Engineering Enterprises. In order to achieve this the primary research question is:

"What potential local pipeline of students could be accessed to study at the new regional engineering education provision in Kent and Medway?",

In seeking to benchmark the current situation, the following sub-research questions have been asked with regards to the 'potential engineering education pipeline':

1. How many students could potentially study engineering at UG level in Kent and Medway?

2. *From where do any potential studys originate?*
3. *Are there any particular engineering subjects that are of particular relevance to the local area?*
4. *Are there any gender differences in post 16 STEM Education?*

RATIONALE

STEM GCE 'A' levels in Further Maths, Maths and Physics are the typical conventional and traditional entry requirements to study engineering degrees in the UK except Scotland. Cornock Cook (2017) reported 9% (440,455 students) of post 16 students studied Physics 'A' level in 2016 of which less than 3% were female. Conversely, in Maths, the gender split in 2016 was 2:1 male to female students, (Carroll & Gill 2017). Earlier reports by the UK Government revealed that in 2014, the uptake of GCE 'A' level in Further Maths was considerably less than that of Physics 'A' level. Indeed, only 2.3% of male students and 0.9% of female students selected to study Physics in 2014 (GOV.UK, 2015).

In 2016, data produced by Cornock Cook (2017) revealed that 5.8% of all post-16 students in 2016 studied a STEM level 3 subject before proceeding to University to study Engineering and Technology. However 21% of such students selected to study other STEM subjects at University with Allied Health and Life Sciences being the most popular; although it should be noted that Allied Health and Life Sciences do not require GCE 'A' level Maths, meaning that the "pipeline" for these areas is four times greater than engineering.

The Destination of Leavers of Higher Education (DLHE) Survey shows engineers earn on average £25,000 per annum and 85% are typically in professional roles (HESA, 2017). Whereas the DLHE survey shows the national graduate employment prospects for Bioscience subject areas, typically 63% of graduates are in professional roles upon graduation and typically earning less than £20,000 per annum.

In an attempt to address the shortage within the Engineering Education Pipeline, a number of Universities have dropped the requirements that Engineering students should possess GCE 'A' level in Maths. Conversely those institutions that do this do, however, generally seek 'high quality' students who typically possess AAA GCE 'A' levels and who are more likely to succeed whichever subject they chose to study (Andrews et al, 2017). Bullough (2017), and Andrews et al (2017) both reported mixed views about the correlation between students with and without Maths GCE 'A' Level in terms of academic progression and retention: Bullough (2017) reported that female students with 'A' level Maths often outperform their male peers. Whilst Andrews et al (2017) conclude Maths 'A' level is not necessarily a barrier to students choosing engineering or barrier to academic progression. Conversely, work by Grayson (2010) suggested that an Engineering Augmented Extended

Degree Programme approach is one solution to the ‘Maths problem’ that has worked well in South Africa.

Equally, the paper by Andrews et al (2017) suggests that students enrolled at pre-1992 institutions have an alarming lack of engineering awareness in the wider world per se. Whereas work by EngineeringUK (2018), displayed below in Table 1, shows that as young people progress through the education system they become increasingly less confident that they could become an engineer.

Table 1: The Percentage of Young People who believe that Engineering might be a suitable career

% Perceive they could be an engineer			
	Aged 11 to 14	Aged 14-16	Aged 16-19
Females	60%	59%	53%
Males	72%	69%	63%

Engineering UK (2018)

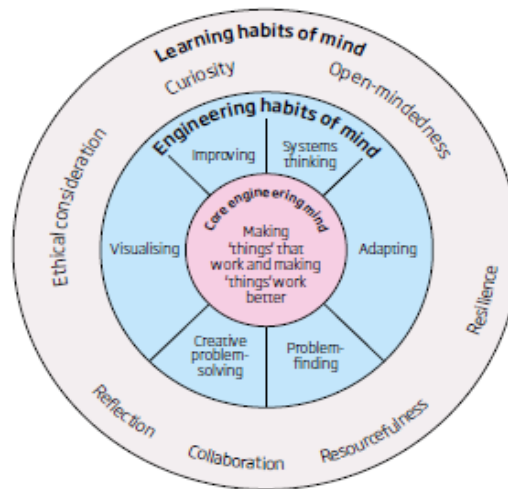
The decline in the percentage of young people who believe they could be an engineer as they progress through their teenage years is augmented by a general lack of Engineering Capital (Andrews & Clark, 2017). This makes it increasingly important GCE ‘A’ level Maths and / or Physics remain pre-requisites to study Engineering at UG level.

Lucas et al (2014) 6 Engineering Habits of Mind in work conducted with young people. School students presenting such traits may therefore be considered to be an untapped source of prospective Engineering Talent, both Kent and Medway and elsewhere.

Another source of potential Engineering Talent could be attracted by the provision of an Extended Degree Programme which commences with Foundation Level studies. In considering this option the KM-EDGE Hub is seeking to attract students who:

1. Have been out of education for a while and are seeking a career change to engineering.
2. Who have not studied STEM at post-16 level but who possess the Engineering Habits of Mind (EHoM) (Lucas et al., 2014).
3. Who wish to study Engineering but whose previous attempts to do so have failed.

Figure 1: Engineering Habits of Mind (Lucas et al, 2014)



METHODOLOGY

Using descriptive statistical analysis techniques an analysis of the 2016-17 HESA data was conducted which examined:

- *How many students applied to study engineering in the UK?*
- *How many students applied to study engineering in the UK and were accepted into HE to study engineering?*

Concurrently a statistical analysis of the 2016-17 Schools Data (Gov.UK, 2018) was cross-tabulated with Canterbury Christ Church University records of School provision of STEM subjects in Kent & Medway to identify the following:

- *How many schools offer between 1 and 6 STEM subjects post GCSE?*
- *How many students are studying between 1 and 6 STEM subjects post GCSE?*
 - How many of these students are female?
 - How many are male?
- *Where does STEM learning occurring across Kent and Medway?*

SUMMARY OF KEY FINDINGS

In the May 2017 there were 8,889 Year 13 students in post 16 education provision in Kent, (KCC, 2017), however the data from Independent Schools is missing.

In 2017 the number of students aged 16-18 at the end of Further Education in Kent & Medway (including students who entered for advanced level 3 qualifications or below-level

3 qualifications) was 21,671 (GOV.UK, 2018). Of these, 11, 452 students studied GCE 'A' levels.

The summary of the statistical analysis of the South East 2016-17 HESA data shown below in Table 2 reveals that only a minority of students in post 16 education in 2016-17 applied for Engineering Programmes nationally and that an even smaller minority were accepted on such courses.

Table 25: Number / Percentage of Kent Students Applying to Engineering Degrees

	Applied	Accepted
Chemical Engineering programmes/courses	40 (0.44%)	10 (0.11%)
Mechanical Engineering related programmes/courses	80 (0.9%)	15 (0.16%)
Software Engineering programmes/courses	35 (0.4%)	0

HESA (2018)

In 2017, 148 Schools and Colleges in Kent and Medway provided post 16 education provision of STEM Level 3 learning (GCE 'A'levels, IBAC and BTEC Diploma). Table 3 shows the number of STEM subjects offered in Kent and Medway

Table 2: Typical number of STEM subject offering in Kent and Medway from Gov.UK (2018) and local knowledge

Kent and Medway			
Number of STEM Subjects	% Schools and Colleges offering STEM Subjects Post GCSE	Percentage of Females (N = 147)	Percentage of Males (Total 141)
0	10.8	22.4	20.3
1	11.5	8.8	8.1
2	8.8	14.4	7.3
3	8.8	11.2	16.3
4	11.5	19.2	13.8
5	26.4	18.4	23.6
6	21.6	5.6	10.6

HESA (2018)

Table 4: Typical Number of STEM Subject offered in UK Schools & Colleges post GCSE

UK (except Scotland)			
Number of STEM Subjects	Percentage of Schools / Colleges	Percentage of Female Students (N = 2760)	Percentage of Male Students (N = 2606)
0	6.7%	13%	12.4%
1	2.9%	3%	2.5%
2	2.7%	5%	2.2%
3	4.8%	15%	5.6%
4	14.6%	23%	14.8%
5	36.9%	32%	32.0%
6	31.4%	9%	30.5%

Table 3 highlights that 16 (10.8%) schools and college (state and private) provide no post 16 STEM Level 3 learning (this is greater than the national average 6.7%).

Table 4 reveals that there are far greater number of male students in Kent and Medway studying STEM subjects in Further Education than female students. This is consistent with the national profile

In 2017, 6178 (54%) female students completed GCE 'A' levels in Kent and Medway, the average number of females per 6th form was 48. Likewise, 5274 (46%) male students completed GCE 'A' Levels in the area with the average number of males per 6th form being 42. Tables 5 and 6 highlight the Female and Male STEM profile in Kent and Medway is consistent with the National female profile.

Table 5: STEM A level uptake in Kent and Medway

Kent and Medway				
A Level Subject	Number of Female students	% Female students	Number of Males students	% Male students
Maths	89	14.3	96	22.7
Further Maths	43	2.5	46	4.2
Biology	86	14.3	82	10.6
Chemistry	71	7.6	75	9.0
Physics	56	3.5	73	12.0
Computer Science	12	0.3	37	3.2

Table 6: STEM A level uptake in UK (Except Scotland)

UK (except Scotland)				
STEM A Level	Number of Schools with Female Students studying subject	% Female students	Numbers of schools with Male Students studying subject	% Male students
Maths	2319	17.6	2253	28.9
Further Maths	1258	2.4	1634	6.0
Biology	2306	18.0	2095	12.7
Chemistry	2183	12.4	2069	13.4
Physics	1677	4.0	2091	15.6
Computer Science	364	0.32	960	3.5

Table 5 indicates that the STEM learning profile in Kent and Medway is consistent in general with the picture in the UK. However, Figures 2 to 7 highlight that geographical concentration of post 16 STEM learning across Kent and Medway is actually disparate. This is supported by the data given below in Figures 8 to 10 which show the challenging nature of the number of STEM combinations available at GCE 'A' level and being offered at multiple locations in Kent and Medway.

Figure 2: Geographical location of A'level Math learning in Kent and Medway

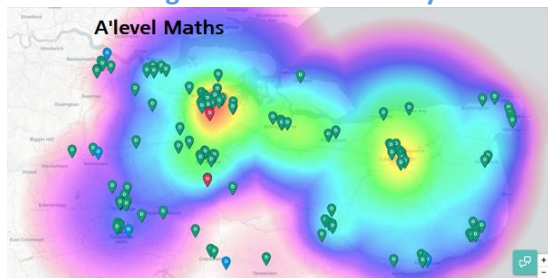


Figure 33 Geographical location of A'level Further Math learning in Kent and Medway

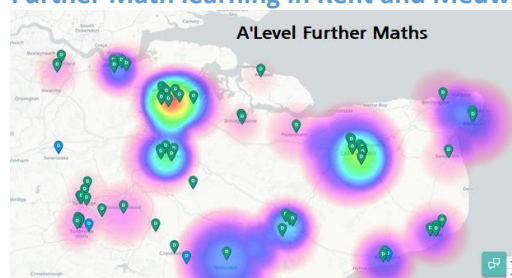


Figure 44 Geographical location of A'level Physics learning in Kent and Medway

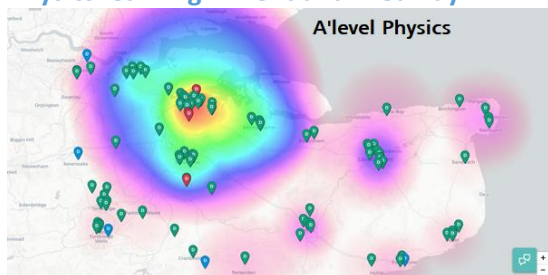


Figure 5: Geographical location of A'level Chemistry learning in Kent and Medway

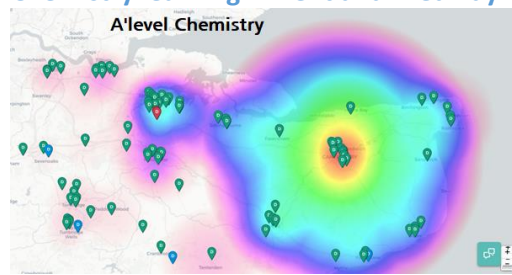


Figure 6 Geographical location of A'level Biology learning in Kent and Medway

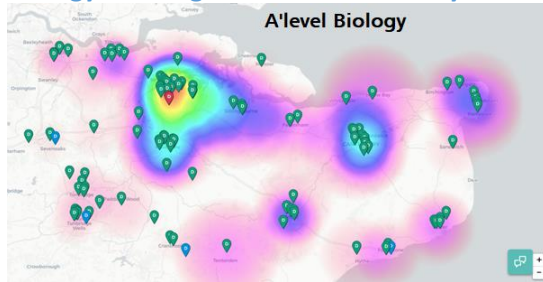


Figure 7 Geographical location of A'level Computing Studies learning in Kent and Medway

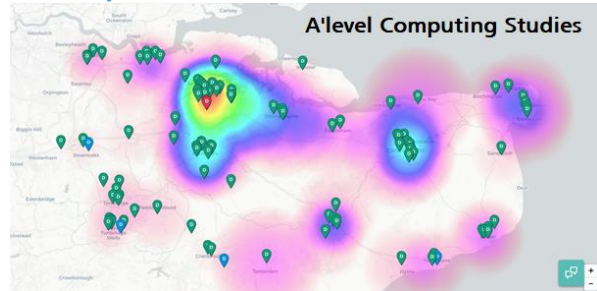


Figure 85 Geographical location of A'level Maths and Physics learning in Kent and Medway

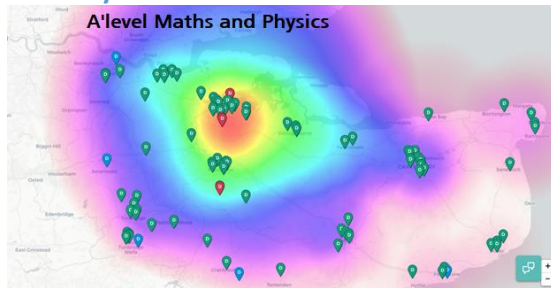


Figure 9 Geographical location of typical STEM A'level combination learning in Kent and Medway

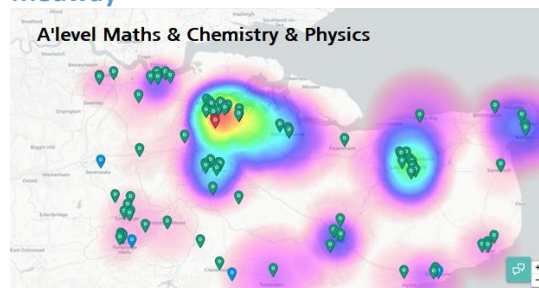
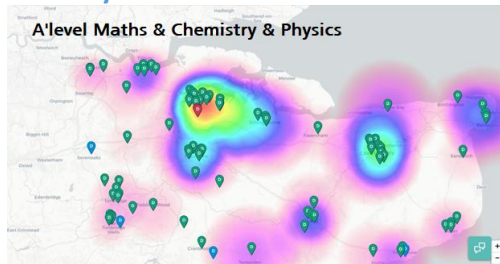


Figure 10 Geographical location of A'level Maths and Chemistry learning in Kent and Medway



DISCUSSION

The above data reveals that on average in Kent and Medway have fewer students of both genders studying GCE 'A' level in STEM subjects when compared to the national picture. Moreover, where Physics 'A' level is being offered in Kent and Medway there is an approximate ratio 3 to 1 Male to Female students (something that is consistent with national picture). GCE 'A' level Maths is the most popular STEM 'A' level, followed by Biology. Yet, whilst the Maths 'A' level ratio in terms of Male to Female is approximately 1.5:1 across the county (and consistent with the UK national picture), Maths is not as popular as an 'A' level subject in Kent and Medway as it is nationally.

The question of why this is the case is somewhat difficult to answer as there are a range of nuanced factors and influencers impacting the situation. One of the main problems is that it is not easy for young people to access GCE 'A' level Physics and Maths in parts of the county, although the exception to this is Maidstone.

It should be noted that Computer Science is the least popular STEM 'A' level both in terms of uptake and being offered by schools across the county and nationally. As Computer Science 'A' level is relatively new (Cornock Cook, 2017) one reason for this is that there simply may not be enough teachers qualified or able to teach the subject to 'A' level standards.

Although nationally, approximately one in three schools offer STEM subjects at post 16, there are 16 schools in Kent and Medway that do not offer any STEM subjects. It should be noted that Kent still operates 11+ Grammar and Non-Grammar education system, and some single gender schools, which will impact the type of post 16 education offered and subjects typically offered.

CONCLUSIONS & RECOMMENDATIONS

In Kent and Medway the STEM GCE 'A' level provision is variable; students have the opportunity to study some post-16 STEM learning (particularly in Maths) but access to other STEM 'A' level combinations is variable (except in Maidstone where it is high). Despite this there are sufficiently high numbers of students studying STEM at post-16 level to potentially fill positions on new Engineering Programmes as they are introduced at Canterbury Christ Church University. Where there are gaps in potential numbers, the University will provide Foundation Programmes, enabling 'non-traditional' students to enter Engineering. One current barrier to this is the fact that because of a lack of previous provision, the numbers of School and College Students who consider Engineering to be a viable option for study at university is traditionally low. This means that there is a real need for purposive and targeted outreach and marketing of the subject to attract new students. In conclusion, by offering 'Engineering' as a subject choice at UG level, Canterbury Christ Church University has the potential not only to change the lives and prospects of individual students, but also to change the economic and industrial face of Kent and Medway. As we live in a world where schools generally do not encourage 'Engineering Habits of Mind' approach to learning, starting up a new University Programme of any sort is a risk, yet, as we move into what may be a post-BREXIT world, it is a risk worth taking!

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Paper 7: Engineering and the 'A' Level Merry-Go-Round

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KEY WORDS. 'A' Level. Alignment. Coursework. Engineering Science. Examinations.

Abstract

The publication of the 2018 'A' level results re-ignited discussion about the validity of changes made to the 'A' level curriculum structure. The system reverted to that with which it began, namely, two written papers taken at the end of the year with, in science subjects, relatively scant attention paid to the assessment of practical work.

As a contribution to the emergent debate this commentary revisits the well documented development by the Joint Matriculation Board (JMB) of Engineering Science as an alternative to 'A' level Physics. It demonstrated that within a two year non-modular framework there was considerable scope for valid and reliable innovation, although some of it was costly.

This paper describes that examination and introduces the literature about it. While it was a small project it had impact beyond its confines. Among other things it was the first engineering curriculum to demonstrate the need for what is now called 'alignment'. It was developed in a hostile climate and failed to gain the support of engineering educators. It raises the question for the engineering community as to what qualities (abilities) it would like the school system to develop. The engineering science examination provides a model against which the new (old) 'A' level examination can be judged.

INTRODUCTION

The publication of the 2018 'A' level results re-ignited discussion about the validity of changes made to the 'A' level curriculum structure, and in respect of science subjects – practical work. The system reverted to that with which it began, namely, two written papers taken at the end of the year with, in science subjects, relatively scant attention paid to the

assessment of practical work. The essay begins with a brief description of the 'A' level system as it existed at the time (1967) when this new development began.

The development took place in a national context in which it was believed that university departments of engineering were not receiving well-qualified 'A' level applicants. Many actions were taken in the belief they would alleviate the problem. These are reviewed briefly.

Within the Joint Matriculation Board were several persons who believed that students were not attracted to engineering because they did not appreciate that engineering required a different way of thinking to science, in particular physics. Moreover, they believed that an examination in Engineering Science could be designed to demonstrate this point and, at the same time, be equivalent to physics. In this way it would be suitable for university entry.

The development and factors impinging on the development of this multiple strategy approach to assessment which, apart from 'A' level General Studies was unique at the time, is described. The system of competency base assessment of practical work was the first to be introduced in engineering in the UK.

The evaluation led to a model of the curriculum that showed the intimate links between, objectives, assessment, instruction and materials, or 'alignment' as it is now called.

This study raises the question for the engineering community as to what qualities (abilities) it would like the school system to develop. The engineering science examination provides a model against which the new (old) 'A' level examination can be judged.

LITERATURE REVIEW

The primary source is a monograph "*A Case Study in Curriculum Assessment. GCE Engineering Science (Advanced)*" (Carter, Heywood & Kelly, 1986). Various papers were published about course work, its evaluation (Heywood & Kelly, 1973), teacher attitudes to project work (Hiles and Heywood, 1972), discovery methods of learning (Heywood, 1976), and criterion referenced grading (Heywood, 2104). An argument that it fulfilled the criteria for a balance system of assessment was also made (Heywood, Carter & Kelly, 2007). The impact of the philosophy of its originator is discussed in Heywood (2012), and its relevance to the proposal for standards based grading in engineering in the US is considered in Heywood (2014)

In addition to the legal requirement to publish the syllabus the JMB published substantial *Notes for the Guidance of Schools. Engineering Science (Advanced)* (JMB, 1973), and unusually it published a series of textbooks to cover each section of the syllabus (JMB, 1969), which were subsequently revised and re-published under the aegis of Project Technology.

Unpublished documents relating to the development of the examination at the administrative and operational levels as well as its evaluation are to be deposited with the archive of the Institution of Engineering and Technology (IET).

Given the continuing debate about 'A' level it is argued that this literature is relevant to engineering education for which reason this paper is intended as an introduction and not a survey.

OBJECTIVE

To demonstrate the relevance of a past development in engineering science at 'A' Level to the current debate about 'A' level.

METHODOLOGICAL APPROACH

Narrative: segmented essay based on a partial review of the literature.

CHANGES IN THE 'A' LEVEL SYSTEM

Recent changes in the Advanced Level Examinations of the General Certificate of Education are said to have returned the structure to what it was when it began. This, it is claimed will restore standards that have been lost. What has been lost? What has been restored? At what expense?

The Advanced and Ordinary Levels of the General Certificate of Education (GCE) were introduced as replacements for the Higher School Certificate Examination and the General School Certificate examination respectively. They were intended for the pupils of Grammar and public schools. A decade or so later a Certificate of Secondary Education (CSE) was introduced for students in secondary modern and technical schools although technical schools could take the 'O' level and sometimes 'A' level examinations.

The prime purpose of the 'A' and 'O' levels was to matriculate a person into a university. In the case of the General School Certificate a student required 5 credits including maths, English grammar, a modern language and science to matriculate. In the case of the new system 3 'A' levels and 1 'O' level, or 2 'A' levels and 3 'O' levels were required.

The curriculum was strictly academic although there was provision for woodwork. Metalwork and Art at 'A' level. Only one university department of engineering is known to have considered woodwork or metalwork as one of the 'A' levels for entry. Generally they were regarded with horror because the university engineering departments wished to escape the craft image of engineering that had come with the industrial revolution. Engineering was regarded as a vocational subject. Sixth forms were rigidly stratified into those taking the arts/languages and those taking one of the sciences/mathematics.

It is not without significance that in policy discussions, as for example those relating to the supply and demand for qualified manpower, with very few exceptions the terms technology or technologists were used in place of engineering and engineer. The government distinguished between technologist and technician in its policy making documents that determined the technical college structure in the 1960's (MOE, 1956, 1961).

In this culture engineering was viewed as an applied science and design was considered to be something that either could not be taught or did not require attention other than through project work.

The examinations were for the most part set by university matriculation boards that were geographically based and, apart from public school students who took the examinations offered by Cambridge and Oxford, most students took the examinations of the Board in their area. The largest examining authorities were the University of London and the Northern Universities of Birmingham, Leeds, Liverpool, Manchester and Sheffield (JMB). The 'A' level to be discussed in this paper was initiated by the JMB. Both London and the independent Associated Examinations Board subsequently offered syllabuses in engineering science that owed much to the JMB initiative. It was developed in a hostile environment and "should be seen in the light of the conflicting views about the nature of the sixth-form curriculum and the different strategies by which a greater awareness of the principles of engineering could be introduced at school level" (Carter, Heywood & Kelly, 1986).

SCHOOLS AND THE SHORTAGE OF APPLICANTS FOR ENGINEERING IN UNIVERSITIES.

The universities continually complained about the shortage of students for engineering. This generated a number of investigations and a committee of inquiry. There were investigations into the attitudes that students had of engineering, and the Colleges of Advanced Technology created to ensure that industry had a continuing supply of engineers for management and technical duties other than research. The study that had most impact was due to D. G. Hutchings of Oxford University. Just prior to the publication of the Robbins Report on Higher Education in 1963 he published "*Technology and the Sixth Form Boy*" (Hutchings, 1963). He reported that on average boys pursuing engineering had lower 'A' level grades than those pursuing science subjects particularly physics. This caused a furor among the engineering profession and schools were exhorted to encourage their best pupils to study engineering.

At the same time it was realised that a number of schools had developed engineering activities for their 'free time'. The extent of these activities was unknown but it was understood they were often of a project kind, and that some schools had persuaded the Cambridge Local Examinations Syndicate to offer an 'A' level on the Elements of Engineering Design. The Institution of Mechanical Engineers enquired into what was happening in 290 schools and found a variety of activities (Page, 1965). Page, who conducted the enquiry, found a range of activities with the majority of them being of an applied science kind. He suggested that these activities made science more attractive and, "it may not be too fanciful

however, to assume that a high proportion of the boys who might be won to science from the arts sixth form by a more creative approach to science would choose engineering rather than science, at the output end of the sixth form”.

During this period a newly founded “Schools Council” following a study by HMI Porter initiated “Project Technology” which was designed for “free time” work in schools. Much favoured by the Engineering Professors it ran for many years during which it part financed the JMB’s attempt to develop an ‘A’ level examination in Engineering Science. A member of its team D. T. Kelly was also a chief examiner and chief moderator for this new examination

JMB ‘A’ LEVEL ENGINEERING SCIENCE

Professor Harry Edels, Dean of the Faculty of Engineering Science at Liverpool University, promoted the idea of an examination in engineering science for two reasons (Edels, 1968). First, he argued that boys would not understand what engineering was about from the study of physics. Second, he argued that engineering was a different way of thinking to science and that an examination had to reflect that way of thinking. He was allowed by the JMB to develop an examination syllabus in engineering science that was epistemologically driven but with the requirement that it would be equivalent to Physics (Heywood, 2012).

His first sample paper followed the same pattern as physics i.e, two three hour written papers from which the candidates had to answer six or so questions, and one three hour laboratory practical. This model was criticised for two reasons. First, that it had fallen into a trap identified by W. D. Furneaux and second, it would not have done so had it taken notice of the recently published (in the UK) Bloom *Taxonomy of Educational Objectives* (Bloom, 1964)

Furneaux who had studied the examination results and personality characteristics of first year students in a university Department of Mechanical Engineering had shown that with the exception of engineering drawing, all the written papers were testing the same ability or quality (Furneaux, 1962). He called this ‘examination passing ability’. A critic suggested that it was skill in the application of certain kinds of mathematics to problems requiring a single solution.

The first criticism of the sample paper was that all the questions were likely to assess the same ‘thing’, and that ‘thing’ would very likely be Furneaux’s ‘thing’. The second criticism was that the assessment of practical was in fact an assessment of the ability to write a written report, and not of a candidate’s ability to do practical work.

Furneaux drew a general conclusion that on the whole examinations were designed by convention with little thought being given to the objectives they wished to achieve. A working party (chaired by this writer) was established by the JMB to draw up objectives for the examination, and suggest methods of examining them. It concluded that a number of significant objectives could not be achieved without a substantial changes in the design of the examination and, the assessment of laboratory work. It argued that that these

objectives could be achieved by the introduction of different types of examination question together with the introduction of criterion referenced assessed project work and enquiry (discovery) based activities. This was the first attempt to design a system of competency based assessment for practical work in engineering in the UK. It designed and implemented a trial written examination among the schools intending to enter candidates for the new examination. It was so successful that the Board and the four schools entering candidates agreed to the new style of examination. Its structure is summarised in the box. It was first offered in 1969.

The working party was also charged with evaluating the examination and assessments. With the permission of the schools and their students it carried out a number of investigations into the functioning of the criterion referenced system of assessment, and the design of examination questions. Apart from that it had available to it the details of the examination and assessment scores. Over a number of years D. T. Kelly carried out studies of the reliability of the coursework moderators assessments (Carter, Heywood and Kelly, 1986).

Table 1: Assessment structure

Sub-test	Objective and technique of assessment, and duration	%of total assessment
Written paper I (3 hours). Section 1	Knowledge and short chain problem solving. 40 objective items, 1 hour	13.5
Section 2	Comprehension exercise (candidates read article from a journal and answer questions on it that show and underlying understanding of the principles. 1 hour.	13.5
Section 3	Project planning and design exercise. 1 hour.	13.5
Written paper II.(3 hours) Section A	Applications of engineering science (analysis and application) 1 ½ hours, 6 from 9 questions.	20.0
Section B	Applications of engineering science (analysis and application) 1 ½ hours. 3 from 6 questions.	20.0
Coursework (throughout the two years of the course). CW I.	Two experimental investigations to be submitted by the candidate for assessment	
Coursework (50 hours of laboratory work) CW II	Project –chosen and completed by the student	20.0*

A year by year analysis using Furneaux's approach suggested that the sub-components of the new-style examination measured different qualities, except that the two that should have correlated did not. The project with its detailed approach to planning, implementation

and evaluation and the written paper designed to test the same skills in planning and evaluation produced the lowest of the inter-correlations between the six components. This was put down to a lack of teaching in respect of this relationship. It was argued by the investigators that formal teaching in engineering design (i.e modelling, optimization, problem formulation and analysis, decision making, specification and judgment with associated techniques such as value analysis) would have increased the correlations between the two papers. To encourage such teaching, articles which ranged over design and value engineering were included in *Topics in Engineering Science*, a bulletin published for schools by the Department of Education of the University of Loughborough. However, while the coordinating committee responsible for the subject was sympathetic to the problem, it did not feel that an examined section on engineering design and management should be included. A major reason for this view was that the syllabus was already overloaded in its commitment to teaching engineering science as an alternative to physics. It did, however incorporate a recommendation in the “Notes for Guidance” which strongly recommended candidates to read Krick’s (1966) book on engineering design. It also negotiated a reduction in price with the publishers. Understanding this problem led to a model of the curriculum that demonstrated the intimate relationships between objectives, assessment, instruction, and materials, or as it is now called ‘alignment’.

At the same time the Committee supported a development from one of its working parties which had designed an ‘A’ level in Industrial Studies suitable for both arts and science students. In an interdisciplinary course derived from a course given in the Faculty of Engineering Science at the University of Liverpool it ranged over the economic, psychological, philosophical problems of industry and included a section on technological design and management. But little outside support was gained for this venture although an alternative at the ‘O’ level had been approved with that title.

The need to ensure that the objectives of instruction were the same as the objectives of assessment led to one of the earliest statements of ‘alignment’ and description of the curriculum process. A decade later it was argued that in addition to the problem of teaching, the type of executive decision making required in the context of an examination is different to that required in the ‘real’ time pursuit of a project, this hypothesis being derived from Sternberg’s triarchic theory of intelligence (Heywood, 2016; Sternberg, 1984).

During the evaluations one of the teacher’s Glyn Price showed that while students could solve a problem mathematically, they did not understand the physics (cited in Heywood, 1989). This was an early introduction to the issues surrounding misperception

THE WITHDRAWAL OF THE EXAMINATION

The examination which ran for fifteen or so years caused the physics examination to adapt to a similar model, and eventually it was merged with physics B as an alternative to Physics A. There were two reasons above all else that led to its failure. The first was the failure of the Engineering Professors Conference to actively endorse it. The second was the small

number of students entering – just over a 100 in each year making it a high cost activity for both schools and the JMB. Related to these was, undoubtedly, the status of subjects perceived to be vocational in the culture of English education. It is predictable that ‘T’ Levels will suffer from the same perception which persists in English society.

DISCUSSION: THE WIDER INFLUENCE OF THE DEVELOPMENT OF JMB ENGINEERING SCIENCE

Carter, Heywood and Kelly (1986) have argued that its influence on education extended far beyond its confines. In the first place it caused the JMB to extend its activities to curriculum development, and to set up a separate coordinating committee outside its normal structures for the administration and development of the examination. Second, variants of its semi-criterion referenced coursework grading scheme came to be widely used. It continues to have relevance. For example, the problems experienced in the development of the scheme and their evaluations strongly support the proposals for the standards based grading of student engineers in the US made by Carberry and his colleagues (Carberry, Siniawski and Dionisio, 2012; Heywood, 2014). Third, criticisms by industrialists that it was based on false models of what it is that engineers actually do led the UK Government’s Employment Department to fund a major study of engineers at work (Youngman et al 1978).

From a research perspective it was able to replicate its analyses over a nine year period. But, it failed significantly to have any major impact on engineering education in spite of substantial evidence in its favour. It raises the question for the engineering community as to what qualities (abilities) it would like the school system to develop. The engineering science examination provides a model against which the new (old) ‘A’ level examination can be judged.

One argument put forward for the current change in the system is that the standards had fallen. It is extremely difficult to judge if this is the case or not. Before the Matriculation Boards were replaced there were some attempts by their research units to compare the performance of examinations widely spaced in time. But these often ran into the difficulty that insufficient data had been retained. Among the data to be presented to the IET archive are item analyses of pilot tests that were taken by first year university students of engineering in the North West. But they are insufficient in number to construct a test. However, since all the multiple choice items that were set are extant it should be possible to construct a test that could be used by ‘A’ Level physics or first year university students that would give some idea of relative standards. Similarly, it would be of interest to analyse the open-ended questions for the degree to which they are perceived to be wicked and mirror actual engineering problems.

The merry-go-round has come full circle back to physics and the idea that engineering is a vocational subject. It is for you to consider if anything has been lost, anything restored, and what the cost-value-benefits to learning are.

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Theme Summary: Educator Development

The final theme in this document begins to give an insight into the complexities of educator development within the Engineering Education field. Three very different papers are included, each one centred on learning and teaching whilst drawing attention to the need for better professional development and educator support within Engineering Education at University.

The first paper by Clark & Andrews, University of Warwick discusses the early findings of a quantitative survey conducted by the UK & Ireland Engineering Education Research Network asking the somewhat controversial research question “*Are Engineering Educators fit for Purpose?*” Twelve key Engineering Skills and Competencies are identified in the paper, four of which the survey indicates that colleagues lack confidence in teaching (Optimisation skills, Spatial visualisation, Building things, Creative design). The paper concludes by arguing that there is a dire need to re-examine how Engineering Educators are trained to teach.

Tombros et al from Queen Mary University London, provide the second paper in this section which focuses on lecturer-student partnerships. Primarily discussing the issues around student engagement in collaborative working, the paper makes an interesting contribution to knowledge by showing how the use of reflective logs can help in Engineering Educator professional development.

The final paper in the findings comes from Lock & Hodkinson, University of Bristol. Focusing on Engineering Education, this paper highlights the need for a ‘Pattern Catalogue’ to enable the recording and sharing of best practice learning and teaching within the discipline.

Paper 1: Are Engineering Educator's Fit for Purpose? An update on the Engineering EDGE

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KEYWORDS: Colleagues' Perspectives: Confidence: Teaching, Engineering Education Index.

FOREWORD: *The Engineering EDGE Project:* *The Study to which this paper refers is currently being undertaken by the UK & Ireland Engineering Education Research Network. A number of colleagues from the Network have thus far made a significant contribution to the development of the Research Tools and have also equally participated in data collection. In alphabetical order, these colleagues are: Dr Esat Alpay: Dr Jane Andrews: Dr Jude Breton: Professor Robin Clark: Professor John Davies: Manish Malik: Dr Anne Nortcliffe: Ahn Tran: Dr Roger Penlington: Dr Peter Wilmott.*

BACKGROUND

Engineering Education in the UK has reached something of a tipping point. At a time when Higher Education is viewed as something of a commodity and is increasingly shaped by unprecedented student expectations and demands (Turner, 2017), many Engineering Educators find themselves facing unparalleled pressures to produce work-ready graduates who are able to succeed in a range of different organisational settings (some of which have yet to materialise) whilst being fully equipped to solve problems (that often don't yet exist).

Within this somewhat volatile environment, a case can be made that there is a genuine need to take a 'fresh look' at Engineering Education within Higher Education; focusing not on the student or industry, but turning attention inwards and looking at the experiences and perceptions of Engineering Educators themselves. Starting with the generic research question of "*What it is that makes a successful engineering educator*" this paper proposes an **Engineering Education Learning & Teaching Priority Index** that is grounded in Engineering Educators' confidence both in their own teaching abilities **and** in their students' level of competence upon graduation. In proposing this Index, this working paper depicts an original approach to Engineering Education, suggesting three particular areas where Educators need to be much better equipped to teach. In doing so it makes a significant

contribution to current debates and knowledge about colleagues' experiences and perceptions of teaching engineering.

METHODOLOGY

Following a Design Based Research approach (Anderson & Shattuck, 2012) the Engineering EDGE Project brings together colleagues from a range of Engineering Disciplines to directly tackle the complexities associated with teaching engineering within contemporary Higher Education. It provides a critical and authentic analysis of Engineering Educators' perspectives, of their confidence in teaching and their confidence in how competent Engineering Students are at the point of graduation.

Very much a work in progress, the Project has four distinctive stages:

1. **Project Design:** A Critical Literature Review: Development of a Conceptual Framework: Development & piloting of Research Tools.
2. **Quantitative Survey:** 174 colleagues from across the UK Higher Education Sector were sampled in the Spring of 2018.
3. **Qualitative Interviews and Analysis:** Currently underway, 40 colleagues have been interviewed. The data is being analysed following a Grounded Theory approach.
4. **Final Mega Analysis of Findings:** Write up and Dissemination.

Based upon the literature review, 13 key 'Engineering-Specific' Skills, Competencies and Knowledge area were identified as being pivotal to success in Engineering. Termed the 'Engineering Edge Expertise Indicators' these are:

- Problem Identification:
- Systems Thinking:
- Discipline Specific Engineering Knowledge:
- Ability to be Adaptable:
- Problem Finding:
- Creative Design:
- Spatial Visualisation:
- Problem Solving: Competence in Applying Technical Knowledge:
- Ability to Make things Work: Building Things:
- Optimisation Abilities:
- Ability to Contextualise Engineering within Society.

The above Indicators were used as the basis of a quantitative questionnaire in which a series of Likert Scales were developed with which to gauge Engineering Educators' perceptions of their confidence in their own teaching ability and their perceptions of the degree to which

students' are equipped with the above key skills at the point of graduation. It is the findings from this part of the Study that this paper focuses.

THE QUANTITATIVE STUDY SAMPLE

A total of 174 colleagues were sampled, the vast majority of whom were from an Engineering background and aged between 40 and 59 years of age. In terms of gender, 68% were male and 30% female (2% did not disclose their gender). The sampling field was 500, meaning that with a confidence level of 95% the confidence interval is 6. Whilst the gender breakdown of the sample does not reflect the wider Engineering Education field whereby just under 20% of academics are female (HESA, 2016), the age distribution of the sample is similar to the wider sampling field wherein the majority of staff fall within the 25-55 age group (HESA, 2016b).

EMERGENT FINDINGS & DISCUSSION

In seeking to address the primary research question of '*Are Engineering Educators are fit for purpose?*' the second part of the survey asked colleagues to rate their own level of confidence in teaching the 13 key 'Engineering Edge Expertise Indicators'. A "Confidence" Likert scale was developed articulating five levels of confidence: Very Confident, Somewhat Confident, Neither Confident or Unconfident, Unconfident. Additionally a 'Not applicable to my teaching' option was provided. During the analysis the percentages answering 'neither confident or unconfident' or 'unconfident' were merged together to form a 'Lacking Confidence' category. The scores were then classified into four distinctive (colour coded) groups in accordance with the percentage of colleagues indicating a lack of confidence in teaching. Figure 1 depicts the coding system whilst Figure 2 depicts the classification and coding for each Indicator.

Figure 1: Classification Coding: Percentage of Colleagues lacking confidence in teaching Engineering Edge Expertise Indicator (Key to Figure 2)

RED	More than 30% lacking confidence
ORANGE	Between 20-29% lacking confidence
YELLOW	Between 10-19% lacking confidence
GREEN	Less than 9% lacking confidence

Figure 2 identifies four areas where around a third of Engineering Educators sampled lacked confidence in teaching: Optimisation Abilities: Spatial Visualisation: Building Things: Creative Design. Conversely, it may be argued that what these competencies have in common is the fact that they are all require a high level of applied 'metacognition' by Engineers (for further

discussion see Borgford-Parnell et al, 2010; Lawanto, 2010). Likewise, it may also be argued that the four areas within the 'Amber' classification (Systems Thinking: Problem Finding: Making things Work: Contextualising within society) also require high to medium levels of metacognition.

Figure 2: Individual Lecture's Confidence in their own Teaching (Depicted in percentages lacking confidence)

AREA SKILL, COMPETENCE OR KNOWLEDGE	RED	ORANGE	YELLOW	GREEN
Problem Identification			10	
Systems Thinking		26		
Discipline Specific Engineering Knowledge				7
Ability to be Adaptable			17	
Problem Finding		21		
Creative Design	31			
Spatial Visualisation	37			
Problem Solving				5
Competence in Applying Technical Knowledge				8
Ability to Make things Work		24		
Building Things	34			
Optimisation Abilities	37			
Ability to Contextualise Engineering within Society		21		

In looking at the data presented in Figure 2, it appears that there is a need for Engineering Educators to consider how to develop "meta-cognition" skills and competencies in Engineering Students. Defined as 'Cognition about Cognition' or 'thinking about thinking' (Papaleontiou-Louca, 2008), from an Engineering Education perspective it is perhaps more appropriate to consider meta-cognition as a 'dualistic' concept whereby 'Meta-cognitive knowledge' is distinguished from 'Meta-cognitive experience' (Flavell, 1981).

Having identified the participants' level of confidence in teaching each of the Engineering Edge Expertise Indicators, the Study then went on to examine Engineering Educators' perspectives of the degree to which students have developed in each area by the time they graduate.

Figure 3 below provides depicts the coding used to classify each Indicator and also acts as a key to Figure 4

Figure 3: Classification Coding: Colleagues' Perceptions of Student Development (Key to Figure 8)

RED	25% or less lecturers believe that upon graduation students have appropriately developed the particular skill, competency or knowledge (Major Concern)
ORANGE	Between 26-50% lecturers believe that upon graduation students have appropriately developed the particular skill, competency or knowledge (Significant Concern)
YELLOW	Between 51-75% lecturers believe that upon graduation students have appropriately developed the particular skill, competency or knowledge (Some Concern)
GREEN	76% or more lecturers believe that upon graduation students have appropriately developed the particular skill, competency or knowledge (No Concern)

The above table depicts the coding system used to classify each of the 13 Indicators. Figure 4, shows lecturers' perspectives of the degree to which Engineering Graduates have developed in each area at the point of graduation. The higher numbers therefore indicate that lecturers are more confident that students possess certain skills, competencies or knowledge (with the highest levels of confidence highlighted in green).

Figure 4: Engineering Edge Expertise Indicators: Lecturers' Perceptions of Student Development

AREA SKILL, COMPETENCE OR KNOWLEDGE	RED	ORANGE	YELLOW	GREEN
Problem Identification				84
Systems Thinking			58	
Discipline Specific Engineering Knowledge				89
Ability to be Adaptable			64	
Problem Finding			70	
Creative Design			58	
Spatial Visualisation		50		
Problem Solving				84
Competence in Applying Technical Knowledge				85
Ability to Make things Work			66	
Building Things			57	
Optimisation Abilities		48		
Ability to Contextualise Engineering within Society		41		

Somewhat surprisingly, in comparing Figure 2 and Figure 4 it seems that whilst Engineering Colleagues believe that upon graduation the majority of students possess appropriate levels of many of the key skills, competencies and knowledge, they lack confidence in their own teaching. This in itself is a matter of some concern which raises questions about Higher Education Teacher Training and the role of Professional Bodies in both accrediting programmes and in supporting academic development.

MOVING FORWARD: THE ENGINEERING EDUCATION TEACHING INDEX

Having analysed the data relating to Engineering Educators' confidence in their own teaching ability and their confidence in graduate students level of competence, the two sets of data were cross-tabulated and used to identify key areas where colleagues' both lack confidence in teaching and feel less confident in their students competence, knowledge and understanding.

From this data, an **Engineering Education Teaching Priority Index** has been developed. Depicted overleaf in Figure 5, the Index uses a 'traffic light' colour coding system to reveal the areas of greatest concern for Engineering Education. These are the teaching of: Optimisation Abilities: Spatial Visual: and, the Need to Contextualise Engineering within contemporary Society. Whilst six distinctive areas are depicted as being of 'medium priority' for Engineering Education: Building Things: Creative Design: Systems Thinking: Ability to be Adaptable: Ability to Make Things Work: Problem Finding

Figure 5: The Engineering Employability Index: Priorities for the Engineering EDGE Project

PRIORITY	SKILLS, COMPETENCIES, AREAS OF KNOWLEDGE
HIGH	Optimisation Abilities Spatial Visualisation Ability to Contextualise Engineering in Society
MEDIUM	Building Things Creative Design Systems Thinking Ability to be Adaptable Ability to Make Things Work Problem Finding
LOW	Problem Identification Competence in Applying Technical Knowledge Problem Solving Discipline Specific Knowledge

CONCLUSION

This emergent study findings reported in this paper represent what is very much a 'work in progress'. Whilst there is much room for debate with regards to the above Index, what is clear is that there are some areas of Engineering Education where University Staff Development Programmes need to better equip colleagues to teach. Furthermore, whilst across the Engineering Education Sector, in accrediting programmes Professional Bodies continue to mandate the contents, context and focus of the Engineering Curriculum, it is perhaps time to look again the within a particular discipline needs to concentrate its efforts,

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Paper 2: Lecturer-student partnerships: a context for innovations in interactive teaching towards concept and writing development

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KEY WORDS: Lecturer-student partnerships, interactivity, reflective practice, concept and writing development.

ABSTRACT

At a time when teaching excellence in universities is only just beginning to obtain the recognition it should always have had, this study offers some insights into an example of good practice. We present a case study about the establishment of partnerships with students and the introduction of innovations in interactive teaching to promote concept and writing development. This paper discusses the impact of these interventions on the students' experience and satisfaction, as well as on the lecturer's professional development. This initiative has allowed the lecturer to reflect on his own teaching practice, philosophy and identity in a moment of his career in which he is transitioning to a *Teaching and Scholarship* contract (as opposed to a *Teaching and Research* contract) in a research intensive Russell group university.

INTRODUCTION

This study emerged as one of the outcomes of a collaborative partnership between the School of Electronic Engineering and Computer Science (EECS) and the Learning Development team (LD) developed over 3 years in a *Whole Programme Approach to Writing Development* (WPAWD) project (2015-18). The project emphasised the role of writing as a learning tool and explored the challenge of developing communication skills. What amplified this challenge with engineering education is the still prevailing traditional image of engineering careers as relying heavily on the development of technical skills and not so much on the development of social, communication and writing skills - considered of tangential importance for the later careers (Beer and McMurrey, 1997; Lievens, 2012). All this despite the longstanding efforts to stress the relevance of these specific skills in the frameworks developed by the bodies responsible for accrediting engineering Higher Education (HE) programmes (areas of learning and skills) and regulating the registration of

professionals in the UK (areas of competence and commitment)² (Engineering Council, 2014^a; 2014^b).

The aims of the WPAWD project were to build an understanding of the context and role of writing in teaching, learning, and assessment, to support the development and dissemination of sustainable innovations related to writing development on a whole programme basis and to contribute to improvements in engagement, retention and success of EECS students. The underpinning theoretical framework for this exploration of the relationship between writing, learning, teaching and assessment was a language as social semiotic one (cf., Coffin and Donohue, 2014; Drury, 2001; Drury et al, 2006; Ellis, 2004; Halliday & Martin, 1993; Lemke, 1990.) As part of the end of the project reporting process, a member of the LD team created a manual describing a wide range of good teaching practices observed and developed in 14 EECS modules at undergraduate level. The case study in this paper was developed within one of those modules: *Operating Systems* – a year 2 module attended by 260 students from computer science and electronic engineering degrees.

RATIONALE

In the context of the module where the intervention took place, students often experience difficulties grappling with threshold concepts and practices (Curry and Hanauer, 2014; Gourlay, 2009; Land, Meyer and Flanagan, 2016). This frequently leads to them seeing the concepts presented and explored in lectures and the experiments conducted in the labs in isolation, and tending to treat each module and the components of each of the modules as ‘islands of knowledge’. In exams, students are challenged by the processes of decomposing problems, breaking questions down and responding to the implicit or explicit parts of questions, often ending up by ‘brain dumping’ whatever they know about the concept.

At the same time, students’ learning practices are hidden and somewhat mysterious for the teaching teams – and to explore what engages students may consume time that lecturers may not have (Entwistle, 1988; Gibbs, 1981; Prosser and Trigwell, 1999; Trigwell and Shale, 2004). Moreover, many academics feel they have not yet resolved the quality and workload challenges involved in assessment design and provision of marking and feedback - for students and staff (Brown et al, 1997; Pilkington, 2011). As a result of all this it can be difficult to tailor teaching practices to the students’ needs, or even discuss and share practices within schools (Biggs and Tang, 2011; Fry, Ketteridge and Marshall, 2009; Ramsden, 2003).

² The *Accreditation of Higher Education Programmes (AHEP)* defines six key areas of learning including a set of additional general skills where we can find the need to apply skills in problem solving, communication, information retrieval, working with others and the effective use of general IT facilities. The *UK Standard for Professional Engineering Competence* acknowledges the role of communication and inter-personal skills in the five generic areas of competence and commitment for all registrants.

The initiative described in the case study is based on the establishment of lecturer-student partnerships in learning and teaching. According to Healey et al (2014, 7) these partnerships are ‘framed as a *process of student engagement*, understood as staff and students learning and working together to foster engaged student learning and engaging learning and teaching enhancement’. Furthermore, these partnerships are perceived as a relationship in which ‘all participants are actively engaged (...) and stand to gain from the process of learning and working together’ and ‘offers the potential for a more authentic engagement with the nature of learning itself and the possibility for genuinely transformative learning experiences for all involved’.

These partnerships often entail some form of collaboration and may involve students working with staff to develop: learning and teaching practices (Cook-Sather et al., 2014), learning through innovative and enquiry-based teaching approaches (Healey et al. 2014) and students’ ‘self-authorship’ contexts (Baxter, Magolda and King, 2004). The collaboration between staff and students challenges the notions of ‘students as consumers’ and ‘just faces in the crowd’ and implies hearing ‘student voice’ (Czerniawski and Kidd, 2011) and enabling students to act as ‘change agents’ (Dunne and Zandstra, 2011) and ‘producers’ (Neary and Winn, 2009). Our study draws on the outcomes of existing research in the field but approaches the context of the development of partnerships from an innovative module–level perspective where a targeted intervention was developed to promote interactivity. This intervention was developed in a particularly challenging context with 260 students from different degree programmes attending the lectures. The aim was to build a teaching and learning environment where students were invited to act not as just faces in the crowd but as partners.

In this sense, this case study explores both the experience of the students and the experience of the lecturer who has used the opportunity to reflect and get involved in an ongoing discussion with the LD team throughout the project about his teaching practice (Bolton, 2010; Larrivee, 2000; Moon, 2005; 2000). This process culminated in an in-depth reflection on his own identity as a teacher in terms of the features identified by Van Lankveld et al (2017): sense of competence, connectedness, appreciation, commitment and future career trajectory as a teacher. All this in a moment of his career in which he is transitioning from a *Teaching and Research* contract to a Teaching and Scholarship contract in a research intensive Russell group university where TEF demands are gaining increasing relevance (McKinney, 2004; Richlin, 2001; Rodgers and Scott, 2008).

AIM

This study addresses a clear need for intervention in terms of the identification of the students’ practices and the design of tailored approaches to develop a set of skills in a specific teaching and learning context. By following a partnership approach, this study was set to involve both students and the teaching team as agents of change. A clear focus was put on the

individual contributions of the students and on the development of opportunities for professional reflection about practice by the lecturer. The question this research set out to answer is whether, and how, student learning can be enhanced by innovations promoting an active and interactive focus on concept and writing development in the context of a staff-student partnership approach to teaching.

METHODOLOGICAL APPROACH

We followed a case study approach (Yin, 2009) in order to conduct an in-depth, multi-faceted, practice-based exploration of the issues involved. There were four phases to the data generation and analysis process:

1. Collection and analysis of eight former students' exam scripts exemplifying a range of responses to the 'short concept questions' which are common in computer science exams. The use of language in three of the answers in each of these scripts was analysed closely using a social semiotic framework (cf., Coffin and Donohue, 2014; Drury, 2001) by the LD worker and the analysis was discussed with the module lead. This linguistic analysis extended our understanding of high and low scoring answers and provided teaching material that was subsequently exploited in the classroom intervention (see next section).
2. Observation of most lectures and some laboratories by the LD worker and ongoing discussion of these observations with the module lead. The observations constituted a form of ethnographic research into the classroom environment (cf., Coffin and Donohue, 2014; Hammersley, 1994, 2006; Lillis, 2008; Pabian, 2014). The ongoing discussions acted as a form of reflection on practice (see references in previous section) for both parties.
3. Writing of an end of project report (after 3 years of the innovation) by the LD team in consultation with the module leads. This report was based on review of the field notes from observation of classroom activities; the materials provided to the students, lecture recordings and interviews of the teaching team by the LD team; student exam performance and overall module marks; and students' end of module survey results and module feedback comments. Pursuing the broadly ethnographic approach referred to above, the report distilled key themes that emerged from the data.
4. Writing of a reflective log by the module lead, using a set of prompts for self-reflection designed by Baptista and Cabral (2015, p. 2) to help higher education (HE) academics explore their identity as lecturers and analyse their practice and professional development:
 - What are my main responsibilities as a teacher in HE nowadays?
 - How do I see myself as a teacher in HE?
 - What is the keyword that defines me as a teacher in HE?
 - How do my students see me?
 - What would I like to change to be a better teacher in HE?

- What are my characteristics that I will (definitely) not change?

THE ENGINEERING EDUCATION PROBLEM AND INTERVENTION

In order to address the problems outlined in the Introduction and Rationale sections of students' engagement with course concepts, the 'invisibility' of writing in computer science and electronic engineering modules, the opacity of students' learning processes, and the workload challenges of providing meaningful feedback on the writing of large student cohorts, the lecturer, in collaboration with the LD team, designed and implemented an intervention which included the following innovations:

- Foregrounding the relationships between course concepts using concept maps (Hay et al 2008; Novak and Cañas, 2008). These were also used in lectures to increase interactivity and to encourage students to explore the relationships between concepts in different ways. For example, print outs of concept maps would be distributed to students with certain concepts, relationships or connections left blank for students to complete as an in class exercise.
- Using in-class quizzes and learning technologies to promote interactivity. For example, students would be encouraged to first answer questions individually and then, if no answer emerged with a clear majority, would be encouraged to discuss in groups trying to arrive at a consensus. This method was effective in encouraging the class to argue about the correctness of answers and led, in the majority of cases, towards the selection of the right answer (Bates & Galloway, 2012).
- Using formative assessment tools (multiple question quizzes) with rapid, detailed feedback. A formative quiz was developed for each of the module's topics (Tropman, 2014), was made available for students to interact with and remained accessible until after the completion of the module exams. Each question in a quiz includes potentially many correct answers and invites students to engage deeply with the material.
- Co-investigating actively with students throughout the term their writing in response to exam questions (using model answers, reviewing samples of student answers from past exams, peer reviewing of student answers provided in in-class activities, working with assessment templates and arriving at marking criteria, etc.).

FINDINGS AND DISCUSSION

The establishment of partnerships between lecturer and students is a process that takes time and demands investment. In this study the process started with the same cohort of students in a previous module in the first semester of the 2nd year taught by the lecturer. Students could see from the first week of teaching that the lecturer was present and available (e.g. attended all tutorial and lab sessions), responded quickly to any kind of questions (in person or in electronic form), made the effort to learn students' names, placed great importance on feedback, used positive feedback to encourage a sense of achievement

and “progress” and approached students as equals, with the overall aim to create an atmosphere of “we are in this together” – partners in learning. According to the lecturer, this forms the foundation which makes the application of other layers (such as interactive teaching strategies) on top easier: the class becomes more receptive to interactive techniques, is more likely to respond to requests for questions and contributions, is less likely to lose focus and discipline.

The synergy of the building of partnerships with interactive teaching strategies is seen as the cornerstone of the lecturer’s teaching philosophy (as put by the lecturer: *“Viewing teaching as an exercise of enabling and constantly keeping open bidirectional communication channels between all stakeholders: the lecturer, the students and other members of the teaching team e.g. teaching assistants”*).

The benefits of the establishment of partnerships with the students – identified by the lecturer as an essential part of his teaching identity – seem to be acknowledged by the students as illustrated by extracts from their comments in the table below. The comments are organised in terms of the four factors involved in the development of teaching identity (Van Lankveld et al, 2017):

Table 1. Factors involved in developing a teaching identity and student comments reinforcing these.

Factors involved in the development of a teaching identity (Van Lankveld et al, 2017)	Students’ comments
Competence	<i>‘Lectures are broken up with questions, examples and expanding on the subject which helps to keep the students engaged’.</i> <i>‘...ability to break things down into small understandable parts. The slides / handouts / supplementary sheets are incredibly helpful and well written...’</i>
Connectedness	<i>‘The lecturer ... seems like he genuinely cares about his students, enough to practically learn everyone’s names.’</i> <i>‘The lecturer actually cares about his students and dedicates a lot of his time helping out.’</i>
Appreciation	<i>‘The lecturer is very approachable and does his best to help students succeed’.</i> <i>‘The fact that we are all getting personal feedback every week is impressive. Teacher is always engaged with the students ready to answer questions.’</i>
Commitment	<i>‘He always has time for students and will go out of his way to see his students achieve.’</i> <i>‘He is very good at communication in terms of e-mail, forum posts and lectures. Even out of hours communication is outstanding’.</i>

Comments in Table 1 highlight a sense of connectedness between students and the lecturer and an appreciation of the partnership approach to teaching and learning. Aspects of the

‘personal’ approach to teaching large classes and to the commitment to viewing students as individuals are highlighted and it is also shown that these can act as motivating factors for students’ increased engagement with the material: ‘...cares about all of his students which makes us want to do well in his module...’. The positive effect of the interventions is also highlighted by students, contributing to developing the lecturer’s sense of competence. Students’ engagement in the process of teaching enhancement was essential with participants reporting opportunities for genuinely transformative learning experiences (Healey et al 2014).

The findings also show high levels of student satisfaction with the end of module survey results all above 85% (themes: *module well-taught, criteria used in marking made clear in advance; adequate feedback; sufficient advice and support; module well organised and that runs smoothly; access to good learning resources*). Students’ comments emphasise the relevance of the innovations to address their needs: ‘*The way it is taught, the lecturer ensures we understand content, using analogies in lectures. Labs help consolidate understanding*’. ‘*If there is a complex concept then he uses multiple examples in order for us to fully understand.*’; ‘*Huge effort is being made by the lecturer for students to have clear idea of the content*’; ‘*Resources provided are excellent as they communicate all degrees of difficulty*’ (i.e., are differentiated).

Although not wanting to put too much emphasis on marks because there are many confounding factors across years (different student cohorts, exam difficulty, personal marking styles, etc.) when looking at student performance in the module before the innovations were first introduced (2014-15) vs. after (2015-18) there have been two clear trends in students’ attainment. First, the overall pass rate has been steadily increasing since the adoption of the innovations (80.4% in 2014-15 vs. 86.1% in 2017-18) with the most significant increase taking place the first year that the innovations were introduced (80.4% in 2014-15 vs. 85.9% in 2015-16). Second, the overall module marks and exam marks in particular have also been steadily increasing (e.g. exam mark average increase from 55.4% in 2014-15 to 57.3% in 2017-18, overall module average mark increase from 55.7% in 2014-15 to 60.8% in 2017-18). These figures should also be seen in the context of rapidly increasing student numbers (an increase of approximately 100 students between 2014-15 and 2017-18).

It should be noted that the first year of innovations (2015-16) was implemented by different lecturer. In the subsequent two years (2016-18), these innovations were continued by the lecturer who is one of the authors of this case study.

These results portray relevant gains not only for the students in terms of their learning experience, but also for the lecturer in terms of professional development.

The findings of the study are consistent with the literature in the field of staff-student partnerships and reiterate the potential module-level interventions to: promote interactivity

in lectures, involve students in the learning and teaching practices (Cook-Sather et al., 2014), give students a voice and an active role (Baxter, Magolda and King, 2004, Neary and Winn, 2009) and enable them to act as 'change agents' (Dunne and Zandstra, 2011).

CONCLUSIONS & RECOMMENDATIONS

In many respects this case study demonstrates the strengths of educational collaboration in general. It has emerged from a mutually enriching dialogue between a lecturer and two academic development staff. It contributes to the discussion about the role of lecturer-student partnerships and more interactive teaching and learning in the enhancement of students' experience, attainment and satisfaction and the professional development of the lecturer.

Our recommendations are:

- Exploit writing as a way of focusing students' attention on the conceptual framework of the module and strengthening their understanding of the relationships between concepts throughout the module;
- Exploit writing and other techniques (such as concept mapping) to foster interactivity among students and between students and the lecturer;
- Perceive the students and lecturer as partners;
- Get to know the students' needs and expectations;
- Use reflection as a tool to tailor the teaching practices to those needs and expectations;
- Use interactive teaching/ learning strategies to stimulate more active learning;
- Take risks and trial innovative approaches.

FURTHER RESEARCH

The issues addressed in this paper may be evaluated and improved through the development of further research in the following areas:

- Diagnosis of students' academic writing skills, disciplinary concept knowledge through the use of tools to evaluate the students' practices focussing on the notions of 'academic literacies' and 'threshold practices' (Gourlay, 2009; Land, Meyer and Flanagan, 2016);
- Relationship between the development of academic writing skills and disciplinary concept knowledge. The interfaces among language studies, science, engineering, and education may be particularly relevant to explore. Our experience in this area has indicated that applied linguistics can serve as a resource for questions, projects and issues situated within the fields of STEM (Curry and Hanauer, 2014);
- Impact of using interactive teaching strategies to promote concept and writing development and enhance learning and academic attainment (Beer and McMurrey, 1997; Biggs and Tang, 2011);

- Establishment of partnerships between staff and students in the process of teaching and learning where students are encouraged to share their needs and expectations and be involved in the design and implementation of interventions (Healey et al, 2014);
- Role of reflection as a process for academics to explore their teaching identity and philosophy and analyse their practice with the aim of enhancing their professional learning and development (Van Lankveld et al, 2017);
- Processes and experiences of partnerships between education and disciplinary specialists (Curry and Hanauer, 2014).

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Paper 3: BrisTLC: A pattern catalogue for sharing of best-practice tools and techniques in engineering education

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SUMMARY

Readers of pedagogic literature will no doubt be familiar with the innumerable ingenious approaches that promise to improve many different aspects of the teaching and learning experience. The problem faced by educators is one of knowledge and awareness – what approaches are “out there” and which are appropriate and relevant to a given educational situation ? There are many potential sources of information, but how can we quickly and efficiently identify approaches that meet specific teaching and learning needs ?

Our solution to these problems is an online pattern catalogue for sharing of teaching and learning best practice. This catalogue provides a searchable repository of effective solutions to commonly experienced problems and challenges within engineering education.

AIM AND OBJECTIVES

The aim of this project is to develop a catalogue of best-practice teaching and learning patterns to help guide and improve educators’ pedagogic practice. This project follows in the footsteps of pattern catalogue work originally proposed by Alexander (1977) and popularised within software engineering by the “gang-of-four” (Gamma et al 1995).

In order to achieve our overarching aim, we must begin by first addressing the following specific objectives:

- Devise a universally applicable classification scheme to consistently categorise patterns
- Design tools to enable effective storage, searching and retrieval of patterns

- Develop systematic & efficient processes to identify patterns and populate the catalogue
- Design mechanisms to ensure the extensibility and sustainability of the catalogue by allowing other educators and researchers to contribute to it.

We are currently developing a tool called BrisTLC as an implementation of our solutions to the above challenges. Once complete and populated with patterns, we will be in a position to evaluate the success of our primary project aim.

By providing a systematic, structured and searchable repository of teaching and learning approaches, it is possible to make finding solutions to problems a much more straightforward activity. Such a pattern catalogue provides an invaluable resource for new lecturing staff looking to develop effective techniques, as well as being beneficial to established staff wishing to revitalise their teaching practice.

RELATED WORK

The concept of a pattern catalogue as described within this paper has some commonalities with the related area of Educational Repositories. Before entering into our main discussion, it is worth briefly considering various software tools available within this domain. These include purpose-built sharing tools such as DSpace (2018), EPrints (2018) and Fedora (2018), as well as open-access public sites typified by the Applied Maths and Science Educational Repository (AMSER 2018).

Such repositories provide much potential for knowledge sharing in an educational context. They typically achieve this by providing a semi-structured organisation of material, based around the use of folders and hierarchies. This is combined with mechanisms for querying of the stored information, often enabled by extensible tagging mechanisms and freeform keyword searching.

Many of these repositories are non-prescriptive in their classification of content, providing no “out-of-the-box” categorisation scheme, but leaving it to users (and administrators) to agree on a suitable structure. As such, these tools are what we can think of as an empty shell - a general-purpose framework within which it is possible to implement a custom classification scheme. It could even be possible to implement the kind of pattern-based approach that is outlined in the subsequent sections of this paper.

It is also worth noting that the current usage of such repositories typically focuses on the sharing of educational material and learning objects. This is somewhat distinct from our

purpose – namely to share more abstract and transferable processes, approaches and best practice.

We should also mention the various teaching and learning approach “glossaries” that are currently available, including those from Rowan (2013), Co-lab at the University of Parma (2018) and the National subject Association for English as an Additional Language (NALDIC 2018). These provide compendiums of teaching and learning techniques applicable to various stages of education (dependant on the focus and domain of interest of the authors).

Such glossaries tend to be based around unstructured free-form text descriptions of the approaches covered. Strategies can be described in variable detail (from a couple of very short sentences, through to many long paragraphs with elaborate diagrams and case studies). Some glossaries impose additional structure on the descriptions - for example the NALDIC glossary provide an indication of rational and motivation through a textual “Why do it” section for each strategy.

It is important to point out that although beneficial to pedagogic practice, the informal and unstructured nature of many of these resources mean that they are only feasible for small-scale repositories. The discursive and free-form text descriptions are not well suited to systematic categorisation and structured query/searching required by large catalogues of techniques.

METHODOLOGICAL APPROACH

Our first task in this project was to devise a classification scheme to aid in the categorisation of patterns for the purposes of organised storage and retrieval. Any such classification scheme must be broadly applicable, so that it may be used to categorise any pattern that may be identified.

To aid in this devising process, we began by taking a small test-set of 10 familiar pedagogic activities (including “Peer Marking”, “Viva examination”, “Poster Session” and “Whole-class feedback”). We then analysed and deconstructed these activities in order to identify a range of key characteristics which we felt defined them. There then followed a number of iterations of sorting and grouping to form these characteristics into coherent criteria. Each iteration involved merging, removing and adding missing characteristics in order to move towards what we felt was a complete and comprehensive set of criteria.

The current working set of criteria used to classify patterns in the catalogue are as follows:

- Phase – The type of activity targeted by the approach (for example “students completing coursework”, or “tutors formulating feedback to students”)
- Motivation – The type of benefit offered by the approach (for example “to make the activity more relevant”, or “to make it faster and more efficient”)
- Input – The type of material upon which the approach may successfully operate (for example “written documents”, or “spoken word”)
- Output – The type of material the approach may usefully generate (for example “written documents”, or “spoken word”)
- Participants – The number of individuals the approach may successfully work with (for example “small groups” or “large cohorts”)
- Context – The environment and social situation the approach may take place within (for example a “lecture theatre” or alternatively “online”)

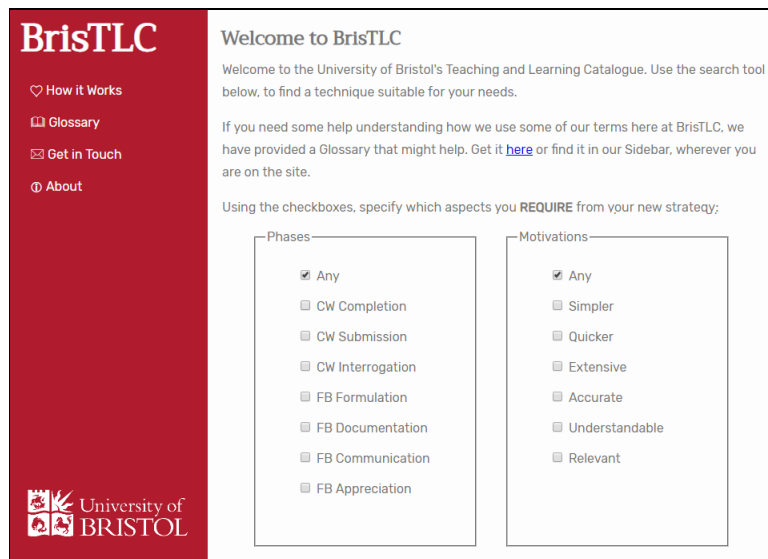
With the above classification scheme in place, it was then possible to begin to populate our pattern catalogue. This was undertaken by analysing and reviewing pedagogic approaches from three different sources:

- Reflection on our own teaching and learning practice
- Resources provided by various higher education Teaching and Learning institutes, for example the University of Bristol Institute for Learning and Teaching (2018) and the University of Reading Centre for Quality Support and Development (2018)
- Review of academic papers in educational publications, for example, Studies in Higher Education (2018), Teaching in Higher Education and Assessment (2018) & Evaluation in Higher Education (2018)

Descriptions and pattern classifications were elicited from all of the above sources in order to compile the current catalogue of 33 patterns. We are also currently considering the feasibility of implementing semi-automated “harvesting” tools to extract patterns from existing online sources of viable approaches, for example University of Leicester Learning Institute’s “Teaching Approaches Menu” (2018).

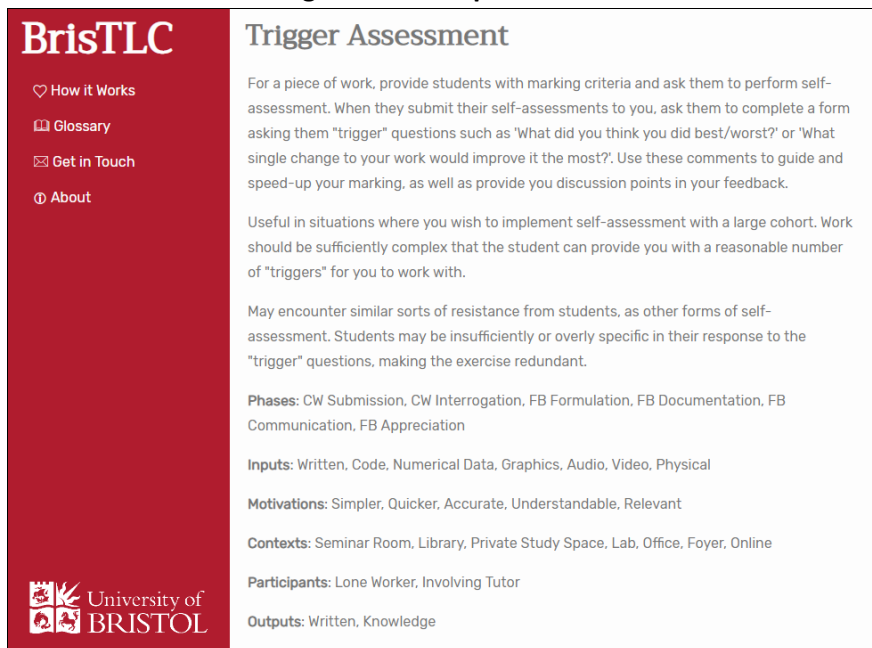
We have implemented the storage, searching and retrieval tools as a Java web application (BrisTLC 2018). Data is stored as JSON documents in a MongoDB NoSQL database. Users can search and retrieve patterns through a web-based interface (illustrated in Figure 1 below). The search mechanism is based around what we consider to be the primary classification criteria, namely “Phase” and “Motivation”.

Figure 1 – Search Interface



The focus of the current version of the catalogue is on assessment and feedback (the aim being to expand this as the project develops). As such, the scope of the current set of patterns includes various stages of coursework completion and submission, as well as marking and feedback formulation and documentation. It is important that the user is able to select a specific objective they are trying to achieve – different approaches will be applicable depending on whether the desire is to expand, refine or simply speed-up a particular teaching activity.

Figure 2 – Example Pattern



The tool generates a list of potentially useful approaches that match the specified criteria. Each pattern returned is described in freeform text, with specific sections covering when

and where it can best be applied and possible negative side-effects of use. Also presented are the various classification criteria used to categorise the pattern to aid filtering and help educators determine if the pattern is relevant to their current situation (see Figure 2).

KEY FINDINGS & DISCUSSION

This project is very much work-in-progress. We have populated the database with a starting set of initial patterns and have developed a prototype version of the search tool which has been demonstrated to practitioners. Initial feedback received thus far indicates that educators see the potential in the approach proposed. The general consensus is that the initial set of patterns currently in the catalogue are useful, but would benefit from being expanding and extending (both in terms of number and diversity). Concerns have been raised regarding the specificity of the search mechanism - results returned often represent a significant proportion of the entire catalogue. This is partly due to the generally applicable nature of many of the patterns stored, but can also be traced to the non-discriminating nature of the classification and search mechanism. Additional work needs to be undertaken in order to improve both of these aspects and to help “tighten up” the relevance of the results to the user's problem-at-hand.

Clearly there is still much work still to be undertaken. Our next steps in this area are as follows:

- Expand and extend the pattern content of the catalogue.
- Further evaluate the classification mechanism (adapting it where necessary).
- Assess the effectiveness of the search features.
- Determine the utility of the whole educational pattern catalogue concept.
- Evaluate the potential benefit to engineering education practice.

Evaluation of this work is currently ongoing with both quantitative and qualitative approaches being undertaken. Quantitatively we have embedded detailed analytics features within the software so that we may investigate usage patterns of the system (including visitor counts, geographical user demographics, common search paths, pattern hot-spots and so on). Our qualitative evaluation strategy will make use of interviews and focus groups to explore the experiences and opinions of users of the system, gaining invaluable feedback to help drive future development.

CONCLUSIONS & RECOMMENDATIONS

Although the pattern catalogue concept is moving in a positive direction, a full and complete evaluation of the impact of this work only becomes possible when the number of actively engaging users reaches critical mass. As with any community there is a tipping point of adoption beyond which that community becomes self-sustaining, with all users contributing and benefitting in equal measure. We must reach this phase in the longer term before we can fully appreciate the benefits and impact of this pattern catalogue approach.

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